AD-A129 044 EUROPEAN SCIENTIFIC NOTES VOLUME 37 NUMBER 4(U) OFFICE OF NAVAL RESEARCH LONDON (ENGLAND) V T STANNETT ET AL. 30 APR 83 ESN-37-4 1/1

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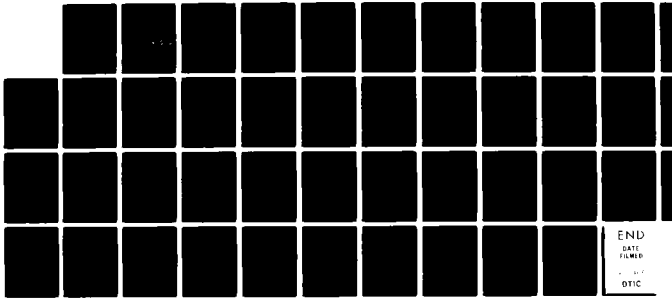

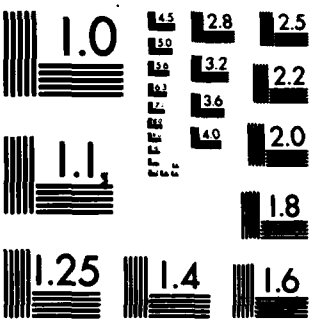

MICROCOPY RESOLUTION TEST CHART
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OFFICE OF NAVAL RESEARCH
LONDON

EUROPEAN SCIENTIFIC NOTES

ESN 37-4

30 April 1983

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 37-4	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EUROPEAN SCIENTIFIC NOTES		5. TYPE OF REPORT & PERIOD COVERED Monthly April
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Vivian T. Stannett and Larry E. Shaffer, editors		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Office of Naval Research, Branch Office London Box 39 FPO NY 09510		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 30 April 1983
		13. NUMBER OF PAGES 44
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

European Scientific Notes (ESN) is a monthly publication with brief articles on recent developments in European Scientific research. The publication is not intended to be part of the scientific literature. The value of ESN articles to Americans is to call attention to current developments in European science and technology and to the institutions and people responsible for these efforts. ESN authors are primarily ONRL staff members. Occasionally articles are prepared by or in cooperation with staff members of the USAF European Office of Aerospace Research and Development or the US Army Research and Standardisati...

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EUROPEAN SCIENTIFIC NOTES
OFFICE OF NAVAL RESEARCH
LONDON

Edited by Vivian T. Stannett
Larry E. Shaffer

Vol 37, No. 4 30 April 1983

BEHAVIORAL SCIENCES

An inexpensive station for psychological testing devised at Hull Univ. does most testing functions completely automatically.

A West German automated screening system has single-cell hit rates on the order of 90%.

CHEMISTRY

Metallic covalent polymers and nonpolymeric molecular metals were the subjects of lectures at a meeting sponsored by the UK's Royal Society of Chemistry--Dalton Division.

COMPUTER SCIENCES

The British government is seriously investigating most aspects of robotics and is determined to make extensive use of robots during the 1980s.

The Groupe de Recherche en Photonique Appliqueé at the Universitéé Louis Pasteur is examining industrial applications of holographic recording and the use of a digital image processing system for automatic fabric control with coherent light.

ELECTRONICS

At University College, London, a simple approach to FM modulation of semiconductor injection lasers has led to significant improvements in low cost, high performance electromagnetic systems. For example, inexpensive, precision control of phased array antennas is now possible, and a conceptually better fiber optic gyroscope has been developed.

NEWS & NOTES

European Scientific Notes is a Class I Periodical prepared and distributed by the Office of Naval Research London in accordance with NAVEXOS-P-35.

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BEHAVIORAL SCIENCES

A COMPUTERIZED TESTING SYSTEM FOR HELICOPTER PILOTS

Self-contained microprocessor systems can be used effectively for psychological testing. Test administration and scoring are usually routine and obviously can be automated. Also, hard-copy data summaries can be produced quickly for selection and training managers, and elaborate data analyses can be done using statistical packages.

As long ago as the mid-1970s, major computerized testing networks were running in the US. An outstanding example was a Navy training system that had a big central computer in Memphis; students in Navy technical schools at San Diego, Chicago, and other places had many training test papers instantly scored and recorded by telephone link to the Memphis computer. Individual lesson planning and much course follow-up was done with management printouts, which also came from the Memphis computer. The configuration, unique for its time, was probably the world's biggest computer-managed instruction system, and it has helped thousands of students through their courses.

Despite such success, there probably will be no more big testing networks. Today, the trend is toward smaller, stand-alone testing systems; the main technical motivation is, of course, the sharply increased capabilities of microprocessors, which now can perform operations that formerly had to be done on big machines. A nontechnical but important reason for stand-alone capability is that the manager and the test-takers themselves often prefer to have their own facility; they like having local, decentralized control rather than working through a distant center. And local control precludes the rare cases of catastrophic shutdown and data loss when the big central system crashes.

The MICROPAT system, developed at the Univ. of Hull, UK, under contract from the British Army Air Corps, is a good example of a self-contained automated test station. It was conceived as a primary selection device for young men who aspire to be helicopter pilots. To start the project, some practical requirements were laid down:

- Addition of new tests and modifications to existing batteries and parameters should be easy.
- All data compilations and long-term storage should be automatic, or nearly so.
- Immediate hard-copy scores from individual candidates should be deliverable for the selection board's use.
- Provision for psychometric research, such as reliability and validity determination, should be an integral part of the system design.
- A candidate should be able to conduct nearly all of the test administration by himself, without a skilled administrator.
- All testing and management procedures should be as "user compatible" as possible. This implied engineering software for "naive" staff users, so that most minor administrative problems could be solved without expert programmers.
- The computer facilities should operate as an "off-line office computer" when not testing candidates.

In addition to the above requirements, it was hoped that the hardware would be rugged enough for military use and could withstand occasional transport from one test site to another.

Hardware selection was fairly difficult, as by 1981 there was a great array of competitive products in the microcomputer industry. For each site, the Univ. of Hull eventually assembled a Z80-based system with Vector Graphics System B, twin Micropolis disc drives, standard 80-column visual display units (VDUs), 64K of dynamic RAM, and various clocks and graphics boards. A special control panel device was fitted to accommodate analogue inputs from joysticks and footpedals; the device also had a small set of special keypads--introduced because some applicants could not type and were not used to keyboard data entry.

A complete MICROPAT test station has two man-machine interfaces: the candidate interface has two VDUs and the input control panel, while an administrator interface has a single VDU and a standard ASCII keyboard. An early decision was made to perform extensive group statistical analyses off-line on a separate main frame minicomputer. This kept the fast memory needs of each station comfortably within 64K, which was available and cheap in 1981.

The test battery for helicopter pilot applicants now has 14 tests, including one-dimensional tracking, multi-task "landing," mental arithmetic, and digit-span memory. Before getting into the test materials, the candidate runs through an INTRO program routine, which makes the applicant comfortable with the machine. In fact, one of the consistent positive findings with computerized testing is that the test-taker adapts to the machine very

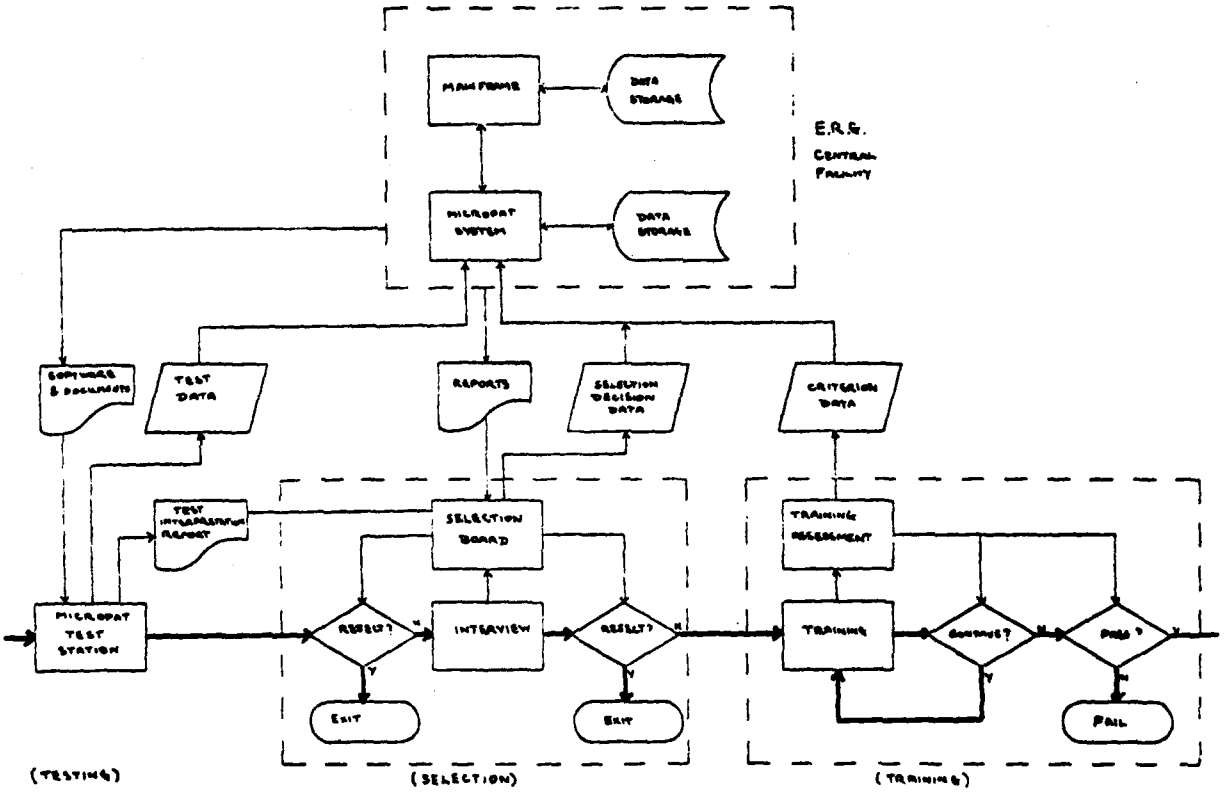

Figure 1. Selection system decision network.

quickly; Suppes and Atkinson observed this 15 years ago with their grade-school subjects in East Palo Alto, CA. After a few sessions, the computers were just another part of school life.

A pilot candidate generates perhaps 2,000 data points as he works through the battery, and the testing system reduces the data to about 30 performance numbers. Management software is on three disks. One of them (BATTERY) has all the test items and the tracking parameters for the analogue tasks. The DATA disk is a temporary store of identification and other data, while the RESULTS disk includes summary (30-point) data on a maximum of 500 people. There is also room on RESULTS for inserting cut-off and criterion values, and other numbers useful in evaluating and revising tests. Security of the individual files is controlled through a coding scheme.

MICROPAT is simple to run. BATTERY is loaded into disk drive A, and DATA into drive B. When the test administrator types "B" into his keyboard, the entire system is "booted" and runs itself through an automatic series of self-checks. The testing then proceeds automatically until the programmed test file on the candidate is full. Depending on local management needs, the individual file can be printed out immediately or it can go into the RESULTS data base. The selection system decision network is shown in Figure 1; MICROPAT outputs are the individual test score records. In addition, a test interpretation report is being planned; as more validity information is accumulated, any of the statistical models that predict likelihood of success could be used.

To revise a test, a special program called SETUP can be used to edit the BATTERY disk. The same program can be used to change parameters for the analogue tracking tasks. The joystick and pedal trials are now genuinely adaptive, and they can adjust track speed according to several adaptation modes (e.g., speed adaptive and control-law adaptive).

MICROPAT can be extended in several directions without major expense. Three-dimensional dynamic graphics is one obvious capability that might be worthwhile in assessing spatial abilities. "Tailored testing" software of

various kinds could be incorporated readily enough, although present management is not especially interested in the saving of testing time. Some of the modifications now under way are aimed at even better user compatibility, rather than at extending MICROPAT into the most advanced psychometric models.

The MICROPAT project staff at the Univ. of Hull continues to write most of their programs in BASIC; they maintain that the language is easy to use with the Microsoft compiler, produces file structures that are easily moved from one machine to another, and is easier for field people to understand.

Many American psychometricians would be impressed with MICROPAT's low cost and apparently high reliability. The project shows that an effective and user-compatible automated test station can be produced without interminable system analyses, expensive hardware, and frequent debugging in the field. The obvious convenience of the system probably means that such stations soon will be installed at various personnel centers in Britain and elsewhere. Certainly personnel researchers will welcome its introduction into the recruitment procedure.

Some psychologists, however, will be disappointed at the rather thin theoretical base underlying MICROPAT. The system is open and empirical, and as it runs and the data accumulate, tests will be revised, dropped, and added. But there is no general psychometric theory underneath all the numbers and all the data reduction. Can it be that decades of research in factor analysis and test theory have not produced models that should be incorporated into an automated test station?

N.A. Bond, Jr.

AUTOMATIC SCREENING OF GYNECOLOGICAL SPECIMENS

Conventional screening of cytological material is done manually using smears or other preparations that are mounted, stained, and scanned by a skilled worker who looks at the material through special microscopic devices. The work is difficult, laborious, and solitary; each slide has many cells and insignificant features on it.

Error rates of the professional cytologists are not well publicized, but there is no reason to think that they are immune to the usual fatigue, biases, and unreliabilities that ordinarily accompany difficult judgments. There is also a tremendous load of test material; in West Germany alone, some 3 million gynecological specimens are examined every year for signs of cancer. For such reasons, many projects around the world have worked toward automatic screening systems that would sort the specimens into preliminary categories. With such systems doing the preliminary screening, only the most suspicious cases would then be examined manually.

Workers at the AEG-Telefunken Research Institute in Ulm (Postfach 1900, West Germany) have produced one of the most advanced systems for scanning slide specimens. J. Schürmann, R. Ott, and E.R. Reinhardt were the major investigators. The research stemmed from studies of polynomial discriminant methods in mathematical statistics (Schürmann, 1977). As the Telefunken facility had long been an industrial leader in electronic image devices, it was natural to apply Schürmann's methods to real biological samples.

The front end of the Telefunken system is a TV microscope which scans a slide with a series of rectangular "windows" (resolution is about 0.5 μm). Each window image is likely to have some information on it: blood cells, epithelial cells, and artifacts and detritus of various types. The classifier machine first "segments" into single-cell pictures the complex material in a half tone picture. The system then assigns the single-cell pictures to one of three classes: D, or "normal"; I, or "suspicious"; and Q, or "malignant." (For the Telefunken project, the 10 categories professional cytologists actually use were collapsed into three.) There can be many cells in each window, and many windows on each slide or specimen. Hence the eventual classification sums up, for a specimen from one patient, all the individual single-cell classifications. The final system output is a number which is supposed to express a "malignancy likelihood," or figure of merit, for the whole slide. Figure 1 shows the flow of information through the system.

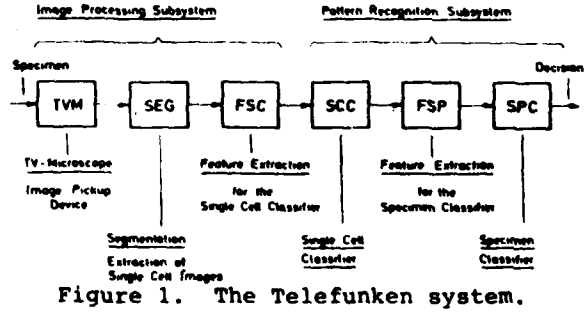

Figure 1. The Telefunken system.

Stated in the rather simple descriptive terms of the preceding paragraph, the system design seems straightforward enough. However, even a cursory look at an actual "dirty" slide indicates not only the extraordinary complexity of segmenting the material on the slide, but also the amount of processing required to make sense of the picture. As an illustration, suppose that a single cell has been segmented out in a given window scene. The cell will have a visible nucleus, and some of the key indicators are in the nucleus. With 20 gray levels for each pixel or element in the nucleus image, a three-dimensional nucleus "surface" with gray level on the Z axis can be computed--with cross-section slices at each of the gray levels, and with numerous functions to be calculated at each gray level slice. The mathematical functions do not, of course, claim to represent the mental processes that a human judge would use to classify the material. Rather, the functions are effective abstractions that might help reproduce the results of human judgments on the same presentation. Minimum mean-square weighing of the functions is done automatically with an adaptive scheme. Various tricks are used to reduce the dimensionality of the processing without losing much validity; for instance, a principal axis transform picks out the most important eigenvectors of what can be an extremely large covariance matrix. From a 360-dimensional measurement vector, the eventual classification system uses only a dozen or so transformed measurements.

Such a complex adaptive classifier has to have a big "learning set" of cells in order to estimate the polynomial coefficients. About 6,000 single cells were used to calibrate the Telefunken system; by the time the training sample had reached that size, the coefficients had settled down reasonably well.

The Schürmann-Ott analytical method permits some informative visualization of real cell discriminant relations. Figure 2 shows a projection of a large sample of measurements onto a plane defined by the first two principal axes. The projection shows that normal (D) cells are rather more concentrated than those assigned to suspicious (I) and malignant (Q) classes.

For a given specimen or patient, swarms of single-cell classifications can be plotted on a triangular display, with D, I, and Q nodes at the three

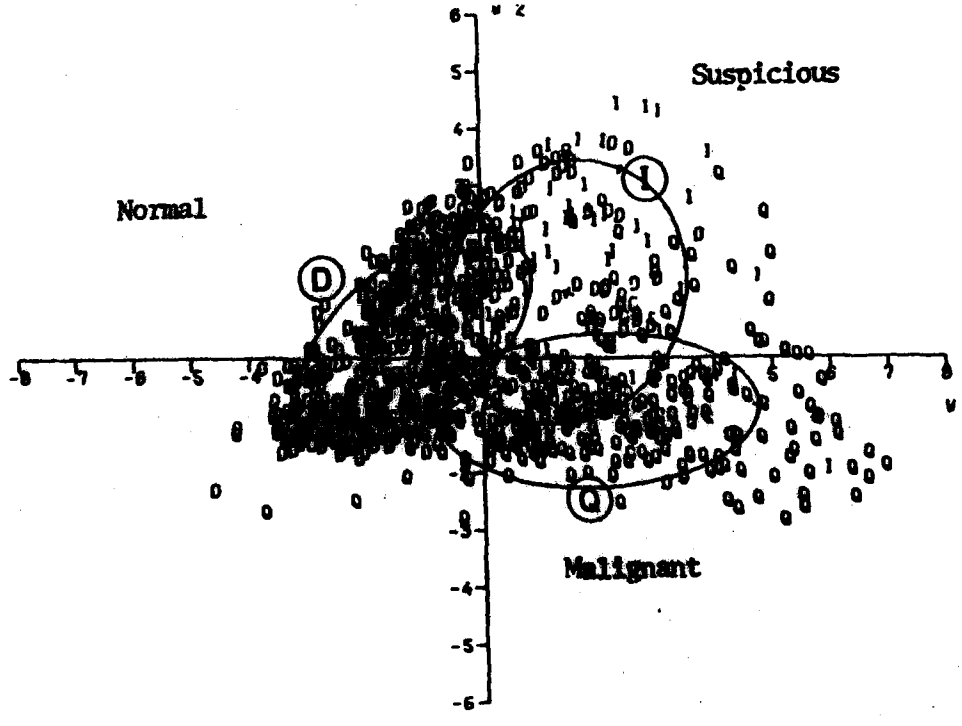

Figure 2. Projection of single-cell measurement space onto first two principal axes.

apexes. Or the projection can be shown in a circular pattern, with certain areas of the circle designated as one class or another. Figure 3 gives the triangular summary plot from one training set of 140 slides. In principle, a plot like this could be made on each slide for an individual patient; a clinician might then base a test or treatment opinion on the appearance of the points around the triangle. (The judgment of "severity" or "risk" from such a triangular point plot would be an interesting cognitive process itself.)

The Telefunken system is clearly a technological *tour de force*. But the key issue is whether it can perform well without extraordinary costs and maintenance. Some results are available from the single-cell classification module, and they are encouraging indeed, as can be seen in Figure 4. On a learning set of 963 single-cell images and a new test set of 962, recognition rates on the order of 90% were observed. Of 595 normal cells it examined, the system called 564 normal; only 26 of the 319 "malignants" were misclassified. When the single-cell classifier was tested further on an entirely independent set of 1,200 normal cells, a false positive rate of only 4.1% was obtained, an extremely good record for the domain.

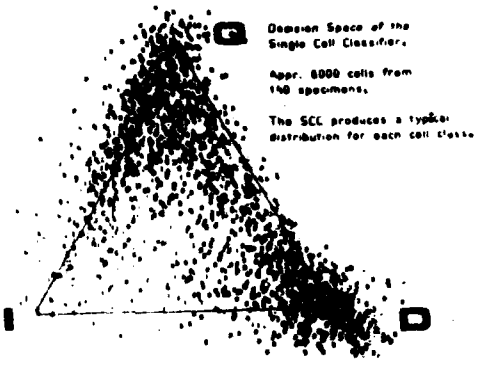

Figure 3. Training set data from 140 specimens (∿ 6,000 cells).

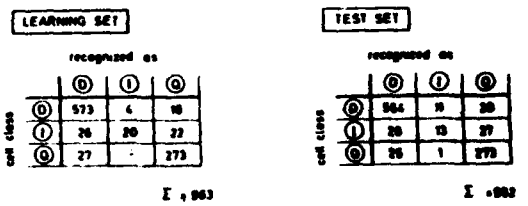

Figure 4. Experimental results for the single cell classification module: confusion matrices for learning and test sets.

The system's classification capabilities are already impressive, perhaps exceeding those of some professional cytologists. A 90% hit rate on real biological material is an unusual achievement. It is difficult to say where further single-cell improvements will come from; the video resolution is already quite adequate, and the mathematics of discrimination is highly developed and well realized in the Telefunken scheme. Perhaps stage-process modeling at the microbiological level will be the best hope for improving further this remarkable screening system from West Germany. Technologists will be watching for results with the summing specimen classifier, and we can expect more attention from the public health community as such systems approach human accuracy in some judgments.

Implementation issues also should be interesting in such a cell screening system. Assuming further improvements and acceptable engineering economics, the system should be ready for practical use in a very few years. Will it be quickly embraced and applied by the public health communities in Germany? From all present indications, implementation will be rather gradual, and the system will have to earn the trust of the various professionals involved. In fact, implementing the system may be as difficult as many of the technical issues that have been faced so ingeniously by the Telefunken researchers.

Reference

J. Schürmann, *Polynomklassifikatoren für die Zeichenerkennung* (Springer-Verlag, 1977).

N.A. Bond, Jr.

CHEMISTRY

METALLIC POLYMERS AND MOLECULAR METALS

Metallic polymers and molecular metals were the subjects of a recent meeting sponsored by the Royal Society of Chemistry--Dalton Division. At the meeting, held in London on 15 February 1983, the society's centennial medal was presented to Prof. A.G. MacDiarmid (Univ. of Pennsylvania).

MacDiarmid gave the main lecture, which reviewed work carried out at the Univ. of Pennsylvania on metallic covalent polymers. Two systems were discussed: the polymeric sulfur

nitrides, $(SN)_x$, and the polyacetylenes (PA). $(SN)_x$ was synthesized in very pure form by solid state polymerization. The product isolates as golden metallic crystals. All bond lengths were found to be equal--1.61 Angstroms--indicating that the polymer is a resonance hybrid. $(SN)_x$ shows typical metallic electrical conductivity properties; the conductivity increases by 225 times when the temperature is lowered to 8°K and becomes superconducting at 0.3°K. Most of the lecture dealt with PA--the undoped cis and trans forms, and p and n doped forms. The use of doped PA films for lightweight rechargeable batteries was discussed; in fact, a small fan, which ran throughout the lecture, was powered by an all-PA battery. (The details of PA chemistry and other features have been described in more detail in *ESN* 37-3:92 [1983].)

Prof. P. Bernier (Universite des Sciences et Techniques du Languedoc [USTL], Montpellier) described some electron spin resonance (ESR) studies on conducting polymers. Very pure cis polyacetylene gave no signal, but the trans isomer did; this characteristic was attributed to defect unpaired electrons. With the polyphenylenes, the ESR depended on the method of synthesis; the all-para polymer prepared from para dibromo benzene gave no signal, whereas the method starting from benzene did--probably because polynuclear structures lead to stable defects. Doping polyacetylene decreased the number of spins to zero at high loadings. No information was available on p-doped polyphenylene. With polyacetylene films, the diffusion constants could be determined using lithium doping and ESR. The overall value was $\sim 10^{-9}$, but only 10^{-17} in the fibrils themselves. In general, doping was found to be very inhomogeneous across the films. The trans polyacetylene component was doped first. ESR could be used to estimate the conductivity with simplified models. The signals from conducting polymers appeared to be mainly due to impurities.

The remaining four lectures dealt with nonpolymeric molecular metals. Dr. K. Bechgaard (H.C. Ørsted Institute, Copenhagen and Universitie de Paris-Sud) discussed the synthesis and properties of a number of planar ion radical salts with metallic and superconducting properties--in particular, tetramethyl tetraselenium fulvalene salts, $(TMTSF)_2X$. Their synthesis from the simplest starting materials was described. Some of the salts showed unusual conductivity-temperature properties, with a sharp maximum at a certain temperature. Most were metal-like at higher temperatures and became superconducting at about 1°K. The temperature was affected by pressure. The planar structures stacked up vertically, separated by columns of anions.

Dr. D. Rosseinsky (Univ. of Exeter) described the electrochemistry and electrocrystallization of tetrathiofulvalene (TTF) salts. He discussed in considerable detail the cell design and other experimental methods. Highly anisotropic metal-like conducting properties were displayed; a number of different anions including SCN^-, I^-, Br^-, BF_4^-, and ClO_4^- were investigated. TTF-Br compounds seemed to have the highest conductivity. Again a maximum in the conductivity-temperature plots was observed. Dr. A.E. Underhill (Univ. College of North Wales, Bangor) discussed some recent studies of unidimensional metallic planar complexes of a number of transition metals. Platinum compounds, particularly the dithiolates, were emphasized. Detailed structure and property studies were discussed. Conductivities up to 300 $(ohms\text{-}cm)^{-1}$ were observed in the best cases. Dr. J.G. Ashwell (Sheffield City Polytechnic) discussed the highly conductive tetracyanoquinodimethane (TCNQ), salts of diquaternized bipyridyl, bis pyridyl alkanes and ethylene, and other quaternary cations. For 12 compounds, Ashwell described the x-ray structures, electrical properties, and stoichiometry--in general, 2 TCNQ to 1 dication. The term "organic alloys" was used to describe the compounds.

Finally, there was a short general discussion on potential industrial uses of metallic polymers and molecular metals. Suggested applications included uses for catalytic electrodes, capacitors, thermal switches, batteries, solar cells, conducting polymer wiring to reduce copper contamination after salvage of automobiles, and microwave absorbers--e.g., to confer radar invisibility.

V.T. Stannett

COMPUTER SCIENCES

INDUSTRIAL ROBOTICS RESEARCH IN THE UK

The British government is seriously investigating most aspects of robotics

and is determined to make extensive use of robots during the eighties. Research in industrial robotics is coordinated through the principal establishment of the Science and Engineering Research Council (SERC) at the Rutherford Appleton Laboratories (RAL), UK. Dr. Peter Smith, RAL's Deputy Coordinator, Industrial Robotics, recently described the research that is under way.

SERC is funded by the UK Department of Science and Engineering and is the largest of five councils in the department. The four main areas of research under SERC are pure science, engineering, nuclear physics, and astronomy. The engineering division was formed 10 years ago; most of its research is coordinated, whereas work in the other areas is directed. Many of the ideas for projects come from the academic community. There are about 20 special areas in engineering, of which industrial robotics is one of the most recent.

In July 1980, the SERC formally announced the program in industrial robotics. The goal was to "leapfrog" the present generation of robots and to support the research needed to ensure that UK industry can take full advantage of the intelligent robot in the mid-1980s. There are five main subject areas in industrial robotics:

- Sensory devices. Work is in vision for inspection, part recognition and reorientation. Research is also being done in tactile sensors for gripping, force measurement and assembly, and optical, ultrasonic, and infrared methods for continuous position measurement. Eddy current sensing is being considered for control of welding.
- Dynamic control. At several sites, work is under way on improving the dynamic behavior of robot manipulators. This is expected to lead to better robot control, producing cheaper machines able to operate faster with heavy loads.
- Mechanical improvements. There is work on a novel hydraulic valve; modular robot design; improved gripper concepts, especially for flexible material and awkward-to-handle objects; and the classification of different practical linkages.
- Safety, diagnostic, and error recovery functions. Work is needed on the design of supervisory software.
- Standards. A steering group with members from universities and industry is supervising off-line programming for assembly. The work includes defining features needed in a high level language for robotic assembly and studying the constraints in linking it with computer aided manufacturing systems, and with individual robots and controllers.

The annual budget for industrial robotics research is £1.2 million; £4 million has been spent since the program began. Smith believes the problem will not be funding, but the limited number of suitably qualified people. Part of the difficulty is that students tend not to enroll in engineering, which is still not so prestigious in universities as science. In addition, industry often does not support innovation.

Eighty-five percent of the funding is devoted to 33 partnerships between industries and universities. In September 1982 a grantees conference (similar to a National Science Foundation conference in the US) was held in Birmingham. Table 1 shows the main centers, their work, and their industrial partners. Several examples of research programs presented during the conference follow.

J.R. Hewit and N. Tan (Univ. of Newcastle-Upon-Tyne) gave a paper on "The Control of Articulated Machinery." The work described covers: (1) the design and manufacture of a small dynamic arm, (2) the development of a new control scheme, and (3) the design and implementation of a microprocessor-based robot controller that uses the scheme. The robot arm has three dimensions of freedom and moves in a plane. The revolute joints are driven by direct-current (DC) torque motors. The robot is equipped with potentiometers, tachometers, and an accelerometer array in the end link. Motor torques can be measured.

The proposed dynamic control method uses the principle of invariance to cancel external disturbances, Coriolis forces, and the effects of modeling inaccuracies. All are treated as unknown quantities acting on the system. Estimates of the canceling torques and forces are derived from measurement vectors of actuator torques and end point accelerations. Because the scheme can work with an inexact dynamic model, the inertia terms used in the feed-forward loop need only be approximations. If the canceling torques exactly match the "disturbance" torques, the feed forward loop reduces to an identity system resulting in linear and decoupled behavior. An outer loop controller can then be applied. Simulation results indicated that dynamic, robust control is achieved.

An experimental robot arm has been built, a control method has been developed, and a robot controller has been designed. The controller hardware circuitry consists of interfacing with

Table 1

Partnerships Between Universities and Industries

Research Center	Industrial Partner	Work
Aberystwyth (Univ. College of Wales)	British Robotic Systems	Research Into Error Recovery for Sensory Robots
Bath Univ.	Walker Crosweller	Automated Polishing of Variable Geometry Components
Cambridge Univ.	Cambridge Electronic Industries	Computer Assisted Industrial Robot Programming Operating and Monitoring Application of Multivariable Control Theory to Robotic Control
Cranfield Univ.	Remek Microelectronics	Low Cost Remotely Located Optical Sensing Robot System Autonomously Controlled Error Correcting Wrist
	Thorn-EMI	Advanced Robot Hand for Assembly
	Tube Investments	Robotic Assembly of Sheet Metal Components
	SERC Robot Language Working Group	A Robot and Workpiece Dynamic Modelling System Development of a High Level Language for Robotic Assembly Tasks
Hull Univ.	GEC Marconi Corah/Marks & Spencer	Interactive Robot Assembly Application of Robots in the Garment Manufacturing Industry
Queen Mary College, London	None	A Second Generation Industrial Robot Vision System Based Upon the Micro Consultants Intellect System Development of Learning Algorithms for Applications in Control of Robot Arms
Imperial College, London	None	A Flexible Robot Arm Fiber Optic Image Processor for Robot Control
Loughborough Univ.	Martonair	Detection, Alignment, and Joining of Flexible Assemblages Digitally Controlled Modular Work Handling System To Investigate the Application Areas of Modular Work Handling Systems
	British Rail	Integration of Robots Within Production System Adaptive Control of Weld Process Penetration and Seam Tracking for Robotic Welding of One-sided Butt Welds
	LK Tools	Robotic Inspection

Table 1 (Cont'd)

Research Center	Industrial Partner	Work
Newcastle Univ.	British Ship Building	Control of Articulated Machinery Robotics Technology Applied to Welding in Ship Building
Open Univ.	None	Structure and Organization in Spatial Kinematic Chains
Oxford Univ.	BL Technology, Fairey Engineering, GEC Electrical Projects	Sensory Control of Fixed Arm Robots for Continuous Path Fusion Welding of Vehicle Bodies
Warwick Univ.	Lansing Bagnall	Free Roving Automatic Industrial Truck

the robot, high speed computing elements, and erasable, programmable, read only memories (EPROMS) containing the robot kinematics and inertia terms. The microcomputer is a Cromemco system 3+ interface. A screen console is connected to the computer, allowing the operator to command the robot. The robot arm and controller are now being tested.

W.K. Taylor (University College, London) gave a paper titled "A Flexible Robot Arm With Fibre Optic Image Processing." A three-section, snake-arm robot terminated by a rotating gripper with parallel jaws has been built; the gripper has eight DC-motor-driven, remotely located, cable drive units and a vertical axis ball-screw prismatic drive, giving eight degrees of freedom (excluding the gripper opening). Each drive motor is controlled by microcomputer-through-interface boards on a time-shared basis. Motor position is measured by incremental encoders feeding 16-bit counters, and error signals are produced to drive the motors into correspondence with the microcomputer instructions. It is sufficient to locate objects and components within the 256 × 256 pixel frame of the television system; the central pixel (128 × 128) is always on the gripper's central axis. When an object is in focus, detectable by the image processor, its distance from the lens is known; the pixel size referred to the object is defined by the lens magnification so that, in effect, the object is covered by a precisely numbered pixel matrix in gripper-referenced coordinates. An image processor (Microvision-100) has been designed to use the sensory feedback to recognize and inspect components and to direct the robot's actions.

To increase the speed of the vision system, the gray levels from a fast video analogue-to-digital converter are processed in real TV scanning time by a parallel digital hardware local operator based on earlier analogue processors; regions of steep gradient magnitude are extracted. This eliminates large changes of background intensities due to uneven illumination, leaving only the essential shape information as binary edge pictures. Algorithms for finding the enclosing rectangle of a shape have been developed, and the coordinates of the rectangle center can be found using simple single commands in the high level Microvision language. Components are first positioned automatically with the rectangle centered on the gripper axis of rotation and at an orientation providing suitable gripping points. The training phase is used to store the shapes of components in fast 64K random access memories (RAMs). For known objects at random orientation and distances, the size of the minimum area enclosing the rectangle is also a measure of distance.

Microvision-100 also can recognize perfect components and detect small defects in components down to sizes of a few pixels. The high sensitivity of Microvision-100 to surface defects can be used to position deburring tools or grinding and polishing wheels at the pixel coordinates of defects.

The present system is controlled by an INTEL 8085 using software developed on Prime Microsim. Installation of a larger microcomputer, INTEL 8086/7/8, is being planned.

"Robot Vision by Parallel Array Processing" was the title of the paper

presented by Prof. D. Michie, Univ. of Edinburgh. An emulator of the parallel array processor CLIP4 at University College, London, has been written at Edinburgh. It is compatible at the assembly code level with the CLIP4 machine. The Edinburgh group has also defined and implemented a high level parallel array language, PARAPIC, which is not tied to a single hardware architecture. The emulator software has been installed at GEC Hirst Research Centre.

Work on programs to solve end games in chess has been adapted to produce a program, ACLS, which can derive a rule for classifying objects. It is being used to produce classification rules for silhouettes of Black Magic chocolates. Parallel array techniques are used to obtain a silhouette from a gray-tone image of a chocolate, and then to extract a number of basic shape measurements (e.g., area, aspect-ratio, compactness). The training set includes several examples of each type of chocolate, with shape measurements and classification. The classification rule is available as either a decision tree or an executable Pascal program.

When silhouettes provide insufficient information about an object, a more subtle representation can be used. In each possible edge location, an edge map contains a number representing a measure of the probability that an object boundary passes through that location. Such an edge map can be produced by simple filtering of the image, but this is rarely satisfactory.

An approach to improving the edge map is an artificial intelligence technique called relaxation labeling. It involves updating the edge probability at each location, with reference to the probabilities at neighboring locations, in order to obtain an improved edge map. The updating is repeated until there is no further improvement. Research on the theoretical basis for the algorithm has been done at the Machine Intelligence Research Unit, Edinburgh. Principles have been developed and applied for designing algorithms that are convergent. Thus the algorithms define the point at which no further improvement in the edge map can be obtained.

Clearly, the work under way in Britain indicates government's commitment to robotics research and to increased use of robots during the 1980s.

J.F. Blackburn

RESEARCH IN PHOTONICS AT UNIVERSITE LOUIS PASTEUR, STRASBOURG

The Groupe de Recherche en Photonique Appliqueé (GREPA) at the Louis Pasteur Univ. uses the technologies of optics, electronics, and computer science in carrying out work in the following main categories:

1. Fundamental research in the interaction of lasers and material.
2. The development of new materials for recording electromagnetic waves.
3. Applications--using light to measure photos and holograms (i.e., metrology), processing information with light, and changing matter with light.

According to Prof. P. Meyrueis and Prof. M. Grosmann of GREPA, photonics uses light to measure, process, transmit, or transform objects or information with the aid of visible or nonvisible electromagnetic waves. Lasers, fiber optics, and their accessories and systems are used for sensing, processing, and using information. Such devices often can be used alone, or combined with each other or with technologies such as electronics and computer science.

In metrology, the use of photonics with robots can be important in improving production. Moreover, photonics can be useful in creating new products (in the biomedical sector, for example), and in offering new solutions to problems. In the future, most sensors used in industrial processes probably will be photonic.

According to Meyrueis and Grosmann, GREPA is involved in several projects concerning applications of photonics.

Holographic Recording

The limited potential of conventional photographic materials has led investigators to explore other possibilities. Photothermoplastic materials for recording are advantageous because low exposure energy is required; high diffraction efficiency is provided; repositioning for recording, processing, and reading is not required; and the recorded information can be erased.

In the experiments at GREPA, Kalle PT-1000S photothermoplastic films were used. The three layers of the film are a transparent plastic carrier, a thin photoconductive layer, and a thin layer of thermoplastic material. The surface is uniformly electrically charged for sensitizing. During recording, the intensity distribution of the incident light produces a conductivity pattern in the photoconductive layer, giving a charge redistribution on the surface of the thermoplastic material. This

produces in the material a pattern of electrostatic forces that is a replica of the light intensity pattern to be recorded.

When the thermoplastic material is heated slightly, the surface is deformed under the influence of the electrostatic forces until equilibrium between the surface tension and the electrostatic forces is obtained. Upon cooling, the surface deformation becomes fixed. The film can then be illuminated with a read-out laser beam. The phase of the beam varies with the stored thickness variation, which corresponds to a phase hologram. Reheating to the softening point erases the stored information.

Experiments with the process lead to the conclusion that thermoplastic recording material has considerable potential for many holographic applications. The material is convenient for rapid in-place recording and reconstructing of large aperture holograms. The researchers state that the panchromatic and sensitive photoconductor gives the medium a response comparable to that of high-resolution photographic emulsions. The thermoplastic also forms relatively efficient thin-film holograms. Investigations show that even difficult holographic recordings with large apertures, such as those needed in industrial applications, can be made routinely.

Digital Image Processing

A digital image processing system can be applied to automatic fabric control with coherent light. GREPA uses an optical Fourier transform device coupled to a minicomputer by a mechanically driven diaphragmed monodiode scanning system. An optical transform produces a very high dynamic image. A dynamic acquisition system was needed to evaluate the possibilities of preprocessing in defect detection--for example, to automate the production of fabrics with a regular texture. A statistical study of optical transforms corresponding to different defects would help in choosing a fast image sensor capable of detecting the minimum amount of information needed to classify the defects. The best picture processing system for a particular application can be designed from a precise knowledge of the required characteristics of the image sensor. Of course, hybrid systems, which combine the flexibility of numerical systems and the parallel processing capabilities of optical systems, require exact evaluation of the digital-to-optical interfaces and image acquisition systems.

An image acquisition system that is very precise was produced with a two-dimensional X-Y mechanical scanner and a low-noise photodiode peripheral to a digital image processing system. A photodiode coupled with an operational amplifier was used as a detector. The output signal was integrated, sampled, and digitized by comparison with a reference voltage; a ratiometric analogue-to-digital converter was used.

The scanner can be operated off-line if one provides analogue outputs of the digitalized intensity level, the position of the detector in the scanned plane, and certain constants determined by potentiometers. When used with an X-Y plot or a scope, such outputs give a three-dimensional view of the image.

Through improvements in the mechanical design, the researchers expect to attain a signal-to-noise ratio of 100, which would allow one to distinguish 1,000 gray levels between 1 and 2^{14}, distributed logarithmically--a performance that compares favorably with that of other detectors.

The system has proved efficient in fabric testing; further work is being done so that the approach can be used in robotics.

J.F. Blackburn

ELECTRONICS

NEW ELECTROMAGNETIC SYSTEMS DESIGN

The University College, London (UCL), Department of Electrical Engineering (EE) is the UK's leading school for microwave and millimeter wave systems research and development. The department had its origin in a famous event: Prof. J.A. Fleming (then of the Mechanical Engineering Department) demonstrated the world's first vacuum tube diode rectifier, upon which the worldwide electronics industry was launched.

University College enrolls 5,000 students (40% are in the graduate school) and has a staff of 600. In addition to EE, the engineering school has departments in civil, mechanical, and chemical-biochemical engineering.

The EE Department recently extended its frequency spectrum to include coherent optics and is currently believed to be the first to exploit new approaches to electromagnetic systems design based on novel frequency

modulation (FM) techniques for semiconductor injection lasers. Among the techniques are low cost but precise control of phased array antennas and a new approach to the fiber optic gyroscope.

Broadbanding Circular Disc Microstrip Antenna

The circular disc resonant patch antenna has been widely studied as a low cost approach to microwave antenna design. In its most usual form it consists of a circular copper disc photolithographically produced on one side of a double-sided printed circuit board. The opposite side of the board is a copper ground plane usually greater than 1½ times the diameter of the disc. The center of the disc is connected to the underlying ground plane by an inductive probe. The capacitance between the two parallel plates (i.e., the disc and ground plane) forms a parallel resonant circuit with the inductive center post. The antenna is typically fed by a probe located off center, connected to the disc, and extending through but not contacting the underlying ground plane. For the typical case, with a dielectric thickness of 0.1 to 0.4 wavelength, the probe itself provides appreciable inductive reactance. Previous designs have always attempted to adjust the dielectric thickness, disc radius, and probe offset distance so that a portion of the shifted resonance curve passes through the 50-Ω matching point. It is not surprising that narrow band operation results.

J.M. Griffin and J.R. Forrest have taken a different approach. Borrowing from methods used in reactance compensation techniques for matching parametric amplifiers, they insert a capacitor in series with the feed signal. The series capacitor value is chosen to series resonate with the inductance of the feed probe at a frequency equal to that of the parallel resonant circuit. The result is a considerable increase in bandwidth. A bandwidth of 35% at an input voltage standing wave ratio (VSWR) <1.5 was obtained with a 6-mm radius disc, 3.2-mm dielectric thickness, and 2.5-mm offset feed probe using Duroid 5870. Largest bandwidths are obtained with thickest separation, but there is a limit beyond which energy is lost to surface wave generation.

The large bandwidths achieved with the double resonant technique greatly reduce manufacturing tolerances and cost, thereby making feasible electromagnetic system designs previously shelved because of high costs. Phased array antenna concepts will benefit most from the technology.

Maintaining Phase Accuracy

Semiconductor microwave power amplifiers offer many advantages to the designer of phased array antennas. Among the most familiar are savings in cost, weight, and size. Conspicuously missing from the list, however, is the phase stability of high performance solid state amplifiers. Typical of a four-cascade bipolar transistor amplifier chain is an intrapulse phase "chirp" of up to 30 degrees. In addition, a fairly expensive voltage controlled microwave oscillator may exhibit an unwanted intrapulse chirp of several megahertz. Superimposed on such inaccuracy is the phase inaccuracy of typical radio frequency (RF) phase shifters within the RF feed manifold.

To circumvent the unwanted phase drift problems of a conventional microwave bipolar transistor amplifier, C.J. Ward, J.R. Forrest, P. Malamis, and A.A. Salles of UCL joined with M.E. Brinson and A.J. Parsons of North London Polytechnic to investigate techniques to provide high power pulses of 100-μs duration at a 10% duty cycle in S-band. The 40-W modules incorporate closed-loop phase control. Their approach is to use a varactor-controlled oscillator followed by a class A, continuous wave (CW), bipolar amplifier and three pulsed, class C, bipolar transistor amplifiers. A 6-dBm signal is coupled from the 46-dBm module output and mixed with a 7-dBm frequency agile synthesized S-band signal. The output is phase referenced against a phase stable 70-MHz signal, and the output is used to provide intrapulse phase compensation. High slew rate amplifiers and fast response phase detectors result in a loop capture range of 25 MHz with a 10 dB stability margin. Phase errors are less than ±2 degrees after 100 ns and within 9 degrees after 50 ns. The approach offers the advantages of fewer amplifier stages, dynamic intrapulse control of phase errors, and individual module phase shifting at the 70-MHz intermediate frequency.

Fiber Optic Control of Phased Arrays

Phased array designs have gradually progressed to include active control over subarrays within the aperture. This permits not only greater flexibility in aperture illumination (thus reducing objectionable side lobes), but also multiple beam formation or monopulse operation. Carrying the approach one step further, Forrest and colleagues

nave been investigating arrays in which each radiating element (and its attendant amplifying module) are given independent control of frequency, power, and phase. Such an approach can effectively exploit the low-cost advantages of monolithic microwave integrated circuits now being developed elsewhere. Such a concept will lead not only to greater radar system reliability, but also to versatility in type and number of simultaneously radiated beams.

Versatility and reliability gained by a large number of independently controlled elements has its price. The technological price is a rather complex system requiring three signal structures: RF manifold, intermediate frequency (IF) manifold, and digital control bus. In addition, power busses are needed. The tolerances required are rather formidable--insertion phase accuracies of 1 degree and insertion levels to within 0.1 dB. Forrest reasons that the best approach to achieving such accuracies is with an adaptive feedback control system with extremely fast slew rates. While the UCL's closed loop controlled module may provide the required RF phase injection accuracy, the complexity of the separate signal manifold structures would make the system prohibitively expensive.

Forrest is convinced that the obvious solution to the whole signal distribution problem is to use fiber optics; RF, IF, and digital control signals are all multiplexed onto a single optical fiber whose metallic protection shields supply the raw direct current (DC) power. A multipurpose manifold of fiber optics is attractive for a number of reasons: light weight, flexibility, immunity to electromagnetic interference, large instantaneous bandwidth, and extremely low loss. Even at frequencies of hundreds of gigahertz, the signal attenuation loss is negligible in the optical fibers. Pursuing the concept further, Forrest began investigating different approaches for using injection lasers to create the phase controlled microwave and millimeter wave signals. Most of his investigation is devoted to using well-known amplitude modulation techniques, although emphasis is now switching to a more promising FM-derived approach.

Amplitude modulation of semiconductor injection lasers at high data rates has been known for over a decade, but it is not without problems. For microwave modulation frequencies, it is necessary to bias the laser well above threshold. The peak performance, however, is generally much below that theoretically predicted. Two factors are believed to be responsible for the degraded performance: carrier diffusion and spontaneous emission, which broadens the spectral output and reduces its height. Spectral broadening can limit the maximum data rate of a fiber optic system because of dispersion induced by the fibers.

Microwave amplitude modulation at the appreciable modulation depths required for efficiency frequently causes the single mode to break into an unwanted multimode structure. For these reasons, Forrest and colleagues have investigated other modulation approaches.

FM of semiconductor injection lasers has received comparatively little attention, primarily because of mode structure difficulties and the relatively poor stability of the emitted frequency. However, improved heat-sinking techniques are providing lasers of remarkably better stability. With the newer laser structures, operation within a single dominant mode is possible, and modulation-induced thermal effects can be neglected as their time constants are much longer than those that would affect the microwave modulation rates of interest. The optical frequency of the laser is given by $f = mc/(2\ell\epsilon_r)^{\frac{1}{2}}$, where ℓ is the length of the laser cavity, ϵ_r is the relative permittivity of the laser material, c is the speed of light in vacuum, and m is an integer representing mode number; ϵ_r is the controllable variable. Two physical mechanisms are involved, plasma interaction and band bending. For small changes of injected carrier density (i.e., of external bias current origin), both mechanisms yield an approximately linear dependence of ϵ_r. Thus it is possible to provide frequency modulation of an injection laser if the modulation levels are limited in magnitude to prevent mode jumping. As injection lasers are now available with individual mode "plateaus" of great breadth, microwave modulation rates do not present a problem unless operation near the edge of a given mode is contemplated.

While optical control of phased array antennas has been investigated at one facility in the US, the UCL team is using a conceptually different approach based on their recent ability to track very accurately two separate semiconductor injection lasers. Figure 1 depicts the moding characteristics of a high quality injection laser and illustrates

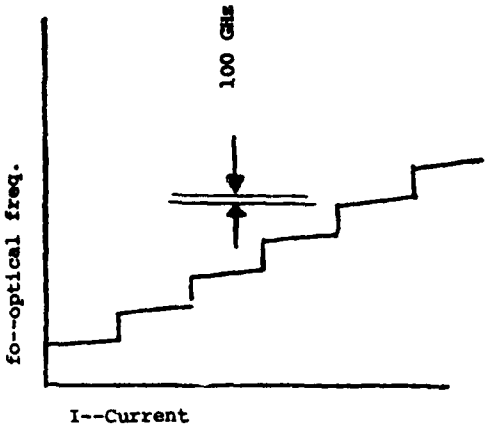

Figure 1. Injection laser mode plateaus.

the optical output frequency variation as a function of input current. The frequency variation within any given mode plateau is a result of the effective change of relative dielectric constant, as described above. It must be appreciated that each mode plateau in some injection lasers spans over 100 GHz of spectrum.

To exploit the moding characteristics for microwave generation, the injection lasers must be selected from adjacent dies on the semiconductor wafer so that the two lasers have nearly identical characteristics. The two lasers also must be attached to a common heat sink so that their small but finite frequency deviation as a function of temperature will be minimized (Figure 2). Both lasers are current-mode biased to the same plateau. Their optical outputs are combined by mirrors and fed to a single mode fiber optic cable which conveys, virtually without loss, the two optical frequencies to the antenna array. (Analysis has shown that a single mode fiber optic cable is needed to preserve the high signal-to-noise ratio of the laser source.) Before entering the fiber optic cable, the two optical signals pass through a partially silvered mirror to couple a small part of the signal onto the fast photodiode detector which can heterodyne the two optical signals and derive an output in the microwave and millimeter wave spectrum. (The eventual use of an optical GaAs metal Shottky field effect transistor as the photodetector may allow overall operation as high as 100 GHz.)

The photodetector output is compared in a phase detector with that of an RF reference, microwave, or millimeter wave source that has frequency or phase modulation imposed on it. The phase detector output is filtered and amplified by an operational amplifier exhibiting extremely high slew rates. The amplifier output, in turn, controls the current bias to one of the lasers. Thus an extremely fast-acting, phase-locked, loop-controlled optical system generates and conveys the microwave or millimeter wave signal without loss to a remote antenna. Additional modulation may be imposed on the optical signal by the second input of the operational amplifier. At the antenna end of the fiber optic cable, another photodetector mixes the two optical frequencies and provides the phase stable reference for the microwave amplifier chain of the array module.

Optical fiber cable dispersion is no problem for use in phased array antenna feed applications as modern fibers exhibit bandwidth length products of 100 GHz·km at 1300 nm and 10 GHz·km at 850 nm. Fiber attenuation can be neglected in overall system analyses as cable runs are very short. However, changes in fiber optic cable temperature do affect the signal propagation delay T as $T = Ln/c$, where L is fiber length and n is the refraction index. For a 10-m length and an optical difference frequency of 3 GHz, a microwave phase change of about 0.1 degree/°C results. If fiber cable lengths are made equal, however, only the differences in temperature between fibers are relevant and (if the fibers are bundled in a common cable) can be neglected.

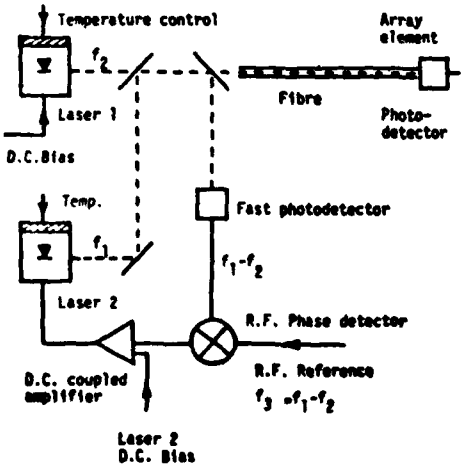

Figure 2. Optical control of array antennas.

More systems work needs to be done, primarily in the optical distribution network. While a single mode optical fiber can safely carry 1 W of power before the onset of nonlinearity, 10-way star couplers introduce losses that make it necessary to insert optical amplifiers in array feeds of many elements. To provide alternative solutions, more sensitive optical mixer photodetectors may have to be developed.

Remote Sensing in Hazardous Environments

I.P. Giles and colleagues have found other interesting applications for the FM injection laser technique described above. The technique is appropriate for detecting and measuring vibrations in locations that are remote, that have high electromagnetic interference, or that are otherwise hazardous. Only one injection laser is used; its output is sawtooth modulated over any given mode plateau. The detection process is somewhat analogous to that of an FM chirp CW radar: a time difference, Δt, between the outgoing reference waveform and that of the reflected target produces an instantaneous difference frequency, Δf, that is related to the slope, S, of the sawtooth modulation by $\Delta f = S\ \Delta t$. For a periodic sawtooth of period T, the resultant output is a line spectrum at intervals of 1/T. Used as an interferometric sensor, Δf is produced by mixing two arms of an interferometer, as in a Mach-Zehnder process. The usable parameter is the ratio of the several line spectrum amplitudes in the central lobe of the spectrum. The position of the peak in the envelope of the line spectrum is Δf. If the frequency is halfway between the mth and the (m + 1)th lines in the line spectrum, then a change in the path difference, σt, changes the ratio, R, of the two lines from unity to $R = 1-2f_m \delta t$, where f_m is the total frequency excursion of the sawtooth source.

Although the baseline sensitivity may not be as high as in conventional interferometers, a resolution of 0.1 μm can be obtained by using a state-of-the-art laser whose mode plateaus exceed 100 GHz of spectrum. The finite loss of sensitivity is more than compensated by the device's other characteristics, including a dynamic range of 10^8, an output independent of source intensity, and absence of drift; electronics are not required at the remote measurement site. The system also can independently and unambiguously read the state of one or more sensors at a considerable range, using only optical inputs and a frequency-encoded multiplexing scheme.

New Approach to Fiber Optic Gyro

The ring laser gyroscope (gyro) was soon followed by various fiber optic gyros that have the advantage of maximized optical path length without ultraprecise optical bench working environments. All have been based on homodyne detection techniques using superimposed phase bias to make the interferometer (detector) as sensitive as possible. B. Culshaw and I.P. Giles are pursuing a different approach. It is based on heterodyne detection, and it not only maintains the basic reciprocity of the interferometer, but it also provides a significant increase in signal processing flexibility because each propagation direction in the loop can be accessed independently. Such separate accessibility provides data allowing one to measure fiber propagation properties as a function of length. With this extra degree of measurement freedom, Culshaw and Giles have found that much system noise is caused by vibration of the fiber ends. The heterodyne approach has other advantages as well; it overcomes 1/f amplifier noise problems and avoids amplitude modulation effects which limit the signal-to-noise ratio in the conventional homodyne approach.

After the problem with fiber end vibrational noise was recognized, it was solved cleverly. Culshaw and Giles knew that in the field the gyro would be subjected to even greater vibration, which they decided to eliminate electronically because mechanical fittings would have been expensive. The heterodyne approach permits the use of a high local oscillator power, which provides the basis for a high signal-to-noise ratio. By modulation coding the transmitting laser source, Culshaw and Giles are able to gate out the unwanted noise produced by the vibrating fiber ends without reducing signal-to-noise ratios to marginal levels. By frequency modulating the laser source as a triangular shaped function of time, the two delayed signals emerging from the fiber ends have frequency differences from the nondelayed source, which is a function of the actual fiber optic length plus or minus any effective differential length induced by rotation of the fiber coil. Any other signals--such as backscatter, reflection, or vibrational noise--appear at different frequencies and can thus be gated (filtered) out.

In initial attempts at frequency modulation of the laser source, Culshaw and Giles used Bragg cells. Unfortunately, the cells caused alignment problems, nonreciprocal effects, and required high drive power. The FM laser

modulation technique used by the optically controlled antenna scheme described earlier is now considered a much better approach. Simple Mach-Zehnder heterodyne interferometer detectors are used to provide stabilization feedback and modulation to the laser. In addition, the detectors give coil rotational rate, which is derived from the frequency difference of the optical signals emerging from the fiber ends after subtraction of absolute path length difference induced frequency.

Other UCL Research

The UCL EE Department is also pursuing several other areas of research and development that may have significant effects on electronics. For example, work is under way on acoustic microscopes (both transmission and reflection), lithium metaniobate deposition by molecular beam epitaxy, Langmuir-Blodgett films, and frequency hopping radar.

M.N. Yoder

SEMICONDUCTOR RELATED R&D AT STL

Research by the Standard Telecommunications Laboratories (STL) includes materials and components, programming and computer services, and telecommunications and electronics. In each area the organization has established a reputation of excellence. Located in Harlow, about 25 miles north of London, STL was once a wholly owned subsidiary of ITT but is now largely autonomous. Of the seven ITT-affiliated research centers in Europe, STL is the largest.

While much of STL's research and development (R&D) supports Standard Telecommunications and Cables, Ltd., research is also done under contract for government and commercial organizations. STL is a vertically integrated organization that can bring to bear impressive and diversified talent to solve a variety of problems. This article primarily addresses work in optics, microwave devices, and semiconductors.

Optics

STL's semiconductor laser group, headed by P. Black, has over 50 people and is the largest in Furope. Over 25% of STL's 800 scientists and engineers are engaged in fiber-optic-related pursuits. The group is rightly proud of their claim that they have developed the world's lowest loss single-mode fiber optic cable, averaging 0.37 dB/km at 1.3 μm and 0.22 dB/km at 1.55 μm. Over 267 km of the cable is now installed in Britain. On an experimental 15-km test link between Ipswich and Martylsham on the eastern coast of England, an average of 0.44 dB/km was measured--a figure including splicing losses. Over parts of the test link, losses as low as 0.29 dB/km were exhibited. Splice losses as low as 0.08 dB have been demonstrated. Although the test link is operating at a 320 Mbit/s rate, it has been successfully tested as high as 560 Mbits/s.

STL research on improved fiber optic systems is generally directed to longer wavelength (e.g., >2 μm) regions where, in principle, attenuations of 0.01 dB/km and lower can be obtained. Even in the 1.55-μm wavelength region of maximum effort, repeater spacings in the 30- to 100-km range are envisioned for underwater applications. Optical fiber materials for the 2-μm region are generally oxide glasses, while those for use at 3 μm are fluoride glass. In addition to the low loss requirements for future optical fiber systems, reliability is of great concern. An overall objective is to have no failures or degradations when the optical fiber is subjected to a strain of up to 2%. Other reliability-oriented research includes the development of a fiber splicing technique based on fusing of the fiber ends by laser "welding."

Among the many advantages of fiber optics is their easy application to remote sensing. For example, the STL group developed a monitor to measure the amount of oil present in water discharged from ballast and bilge tanks aboard ship. The device operates by detecting the light scattered over a given path length of the fluid being measured. It is the only monitor of its kind to receive the approval of the Intergovernmental Maritime Consultative Organization.

Fiber optics technology is not without its problems, however. It has yet to demonstrate the information carrying capacity of a coaxial (coax) microwave cable; eight-fiber cables are being built to operate in a multiplexed manner and thus overcome the problem. But for short installations (e.g., inside a vehicle), the total cost of the fiber-optic-based system probably never will compete with approaches based on monolithic microwave integrated circuits and coax cable. Fiber optics will be used most over long distances, so the very low fiber losses can be exploited.

Another problem is that while the fibers can be used as sensors of magnetic field, pressure, temperature, and

acoustics, the many mode responses often cause unwanted (e.g., acoustic) signals to modulate the wanted (e.g., pressure) signal. The problem of greatest concern is to develop a technique to separate the various signals from each other. One approach STL found promising is to insert into the line a short length of fiber whose response to a particular desired signal (e.g., pressure) may be much greater than that of the remainder of the line. Such techniques, however, usually result in higher losses for the total line.

One of the much-touted advantages of fiber optic cables is that they are intrinsically more secure than microwave/millimeter-wave-based systems; their leakage-radiated signal is much lower than that of coax cable. Even then, no system is totally immune to surreptitious attack. While a fiber optic cable may be physically cut and a signal tapping splice installed, such an overt act is easily detected by the reflection of the signal after the cut and before the splice is completed. Using reflectometry techniques, even the location of the cut can be easily determined.

However, it is much more difficult to detect a surreptitious signal tap made further down the cable and completed before the up-cable cut is repaired. If the down-cable tap is reasonably good, only link-long physical inspection techniques are likely to detect such a tap. Another difficult-to-detect tap is one made by slowly acid etching away a very small cross-sectional area of the fiber and installing a fiber optic tap at that point. STL has just patented an approach that provides a method of detecting surreptitious fiber tapping: the information-carrying fiber is coaxially encircled with a guard ring fiber. To tap the information-carrying fiber, the guard ring fiber must be totally pierced. The guard ring fiber carries a reflectometer-type pulsed signal, which immediately detects the presence and location of the tap. Even a down-cable installed tap of the most precise kind is detectable.

GaAs Monolithic Integrated Circuits

R&D in GaAs monolithic integrated circuits is directed by I. Vance and includes work in both the analogue and gigabit logic areas. Although most research is digitally oriented, significant analogue work is being done. Vance's group started with depletion mode metal Shottky field effect transistors (MESFETs) as the active element basis of many of their integrated circuits (ICs), fabricating devices characterized by control gates of 1.0 µm x 300 µm. A 2-dB noise figure at 9 GHz with an associated gain of 9 dB was achieved. In one of the first successful monolithic IC (MIC) efforts, a GaAs charge coupled device (CCD) was demonstrated to have an 860-MHz sampling frequency and a 400-MHz actual analogue bandwidth.

Digital ICs are made of very thin channel, normally off enhancement mode FETs. Using 400-µm-thick semi-insulating substrates, active layers of both arsenic trichloride-based epitaxy and ion implantation have been fabricated. In the latter method, silicon is implanted and annealed at 900°C for 15 to 30 minutes by the capless proximity method in an arsenic atmosphere. Gate recess is by the anodic etch method, which controls the product of the number of carriers and the channel thickness. The approach provides an impressive transconductance of 120 milli Siemans/mm gate periphery. This figure is all the more impressive as it represents enhancement mode devices rather than depletion mode devices. Gate lengths are nominally 1.0 µm.

One of the first MICs to be fabricated with the above technology was a 50-FET, 24-gate, 5/6 divider circuit. It operates at a maximum frequency of 650 MHz and dissipates 8.8 mW. Its control gates measure 1.1 x 25 µm. Drain loads are conventional resistors; nonlinear loads should further improve circuit performance.

Current gigabit logic work includes a multiplexer capable of frequency multiplexing eight 140-MHz channels into one 1120-MHz output channel. Clever circuit design implements this device in only 100 logic gates. Enhancement mode operation eliminates level-shifting circuits and their wasted power. The multiplexer should operate with but a fraction of the power required for equivalent fiber optic circuits with equal information transfer capacity.

Materials

It has long been common knowledge that the phase transition from alpha tin (α Sn) to beta or metallic tin (β Sn) occurs at 13°C. Growing α Sn has been difficult as the traditional approach of transformation from metallic tin in a solvent solution such as mercury must be done below the phase transition temperature. The large open lattice of the diamond α Sn structure creates a 20% volume expansion during the transformation growth; temperature gradient control is difficult, and impurity incorporation is prevalent. Using

isoelectronic substrates of indium antimonide (InSb) and cadmium telluride (CdTe), molecular beam epitaxy experiments at the Royal Signals and Radar Establishment have led to a striking finding. As would be expected, Sn heteroepitaxially grown at 25°C on InSb or CdTe substrates incurs a uniaxial lattice constant stress. The substrate "pins" the lattice constant (near that of the substrate) close to that of α Sn and considerably above that of β Sn. The result of the pinning-induced stress is that the α to β phase transition increases from 13 to 70°C.

Prof. C.H.L. Goodman of STL reasons that the pinning-induced stress not only will enlarge the band gap of α Sn, but also will reconfigure the band structures so the minimum gap is shifted to a point in momentum space very close to k = zero. Thus the bandgap of uniaxially stressed α Sn is nearly direct. The magnitude of the bandgap will, of course, be stress dependent and therefore adjustable in terms of the substrate used to pin the lattice constant. Photovoltaic response has been observed at 0.12 eV (10.4 μm) when held at 77°K. Infrared absorption measurements indicate that the stressed material is a semiconductor and not a semimetal as had been assumed. This could make possible a new type of photodetector in the 10- to 14-μm spectrum. As polar optical phonon scattering would be absent, the material might exhibit very high mobility and charge carrier velocity. Although photoholes produced by radiation in the 10- to 14-μm spectrum should behave normally in stressed α Sn, its unusual band structure should ensure a peculiar property; holes produced at the Γ-point should exhibit negative effective mass.

Goodman carries the conjecture further; using GaSb substrates, a Ge-Sn structure analogous to that of Si-C can be grown. At room temperature the L and Γ gaps of Ge-Sn should coincide, providing a resultant effective bandgap of 0.65 eV. Many possibilities for devices become obvious: double heterojunction lasers in the 4-μm band, cold FETs (high electron mobility transistors), and magnetoresistive devices. It must be stressed that the direct nature of the stressed α Sn structure has not yet been conclusively proved. Piezoresistance and other band measurements sensitive to band symmetry are needed to clarify the semiconductor-semimetal determination.

Other materials studies include a variety of arsenic trichloride epitaxial reactors and ion implantation techniques, which contribute to the exceptionally high enhancement mode FET transconductance figures reported above. B. Barry has developed a simple but effective technique to determine the cleanliness of a semiconductor wafer surface. He is using an apparatus that measures the contact angle of a drop of pure water on the semiconductor surface and correlates the angle with surface cleanliness.

M.N. Yoder

MANAGEMENT SCIENCE

THE INSTITUTE D'ADMINISTRATION DES ENTREPRISES

The Institute d'Administration des Entreprises (IAE) is the management science school of the Université de Droit, D'Economic et des Sciences D'Aix-Marseille. As its name suggests, the university has two main campuses, one in Marseille and the other in Aix-en-Provence, France. Approximately 25,000 students attend the university.

The IAE, founded in 1957, supports a variety of graduate degree programs; two professional-education master's degrees are offered. One is designed to provide a grounding in management for students with master's degrees in other (mostly technical) areas; in addition, there is a part-time program for executives. Roughly 200 students are enrolled in the programs each year. Nondegree, continuing education programs in management sciences are conducted at the Centre de formation du Clos Guiot, about 4 miles from the Aix campus. The facility can accommodate 300 students.

There is also a "standard" master's program with about 30 students per year. Five areas of concentration are available: auditing and accounting, personnel management, marketing, services management, and quantitative methods and computer science. Most of IAE's doctoral candidates come from this program; last year, seven PhD degrees were awarded by the institute.

For several reasons, the IAE is unique within the university. First, it has a relatively young faculty; 12 of the 22 members of the "doctoral faculty," are not yet 38 years old. Second, 14 members of the IAE faculty received graduate degrees from universities in the US; others have spent leaves or sabbaticals at US universities. Third, the institute has convinced several large industrial companies to name IAE as recipient of an industry tax that the French government levies on businesses. This has generated what amounts to private funding for the institute, which therefore can

maintain a very good departmental library (receiving over 200 journals in management science and related areas), adequate secretarial support, telephones, offices, and some official travel by IAE faculty. I was told that many of the benefits and activities simply would not be possible with ordinary funding from the university.

For example, many faculty members in French universities apparently have no office, and thus no telephones, computer terminals, or office hours. A good departmental library is important because French universities often do not own, or even manage, the main libraries on or near their campuses. Instead, the libraries are operated by a separate civil service, which may be slow or reluctant to respond to acquisition requests from university faculty members. The IAE library has formed cooperative agreements with other European libraries having significant holdings in management science, and the departmental library staff is currently developing a data base with information about such holdings in libraries throughout France.

IAE's young, entrepreneurial, US-oriented faculty is deeply involved in research on a variety of management science problems. Prof. Michael Montebello directs the activities of the institute. Prof. Pierre Batteau is research director, a position that corresponds roughly to assistant dean of the institute, and is chairman of the finance department within the institute. Batteau is working on problems related to the theory of collective choice, which is concerned with how individual preferences are (or should be) aggregated in the process of making decisions on public issues. In recent years, there has been considerable interest in the question of whether there exists for each individual a "dominant strategy" that is independent of actions taken by other individuals in the society. In a game, a strategy is dominant for a player if, regardless of the actions taken by other players, he has no incentive to move away from that strategy. If collective choice procedures can be designed so that any information about others' choices is of no value to the individual, then using the procedure presumably will cause each individual to reveal his true preference, rather than "playing games" to influence others to adopt a position.

Even with restrictive preference patterns motivated by economic considerations, generally one cannot construct an incentive-compatible mechanism that guarantees the existence of dominant strategy equilibria. Thus, there has been consideration of procedures allowing private compensation once the public choice is made. For example, once a decision has been made to build an airport at a certain location, people affected by the project might receive compensation for being inconvenienced. Using rather strong assumptions about the utility function over public and private goods, recent research has characterized compensation schemes that are incentive compatible. Batteau is working on extensions of the results to wider classes of utility functions.

Dr. F. Boctor, a member of the IAE doctoral faculty, is supervising work in industrial management. Boctor's current research concerns job-lot scheduling problems; the objective is to schedule steps in making products so that overall costs are as low as possible. Lot scheduling problems can be classified according to the nature of the demand for the products (deterministic or stochastic), the planning horizon (finite or infinite), the number of products (one, two, or several), and the number of production facilities (or "machines"). A deterministic demand can be either constant or variable--the static and dynamic demands, respectively. In a recent paper dealing with the two-product, single-machine, static demand, infinite horizon lot scheduling problem, Boctor (1982) discussed the feasibility of schedules. He also described a procedure for obtaining the optimal lot sizes for the two-product case and showed that a necessary condition for the feasibility of n-product schedules is that each cycle time be an integer multiple of some basic cycle time. Based on this necessary condition, Boctor has developed a heuristic for the single-machine lot scheduling problem. He assumes that:

- Only setup and inventory holding costs are considered
- Demand rates and production rates are deterministic and constant
- Setup times and costs are independent of the processing order
- The machine cannot process more than one product at a time
- Products are manufactured in repetitive cycles, and the batches of the same product are of equal size and are equally spaced through time
- Shortages are not allowed.

The problem is to determine product cycle times that satisfy the above conditions and minimize the sum of the setup and holding costs. Boctor's "G-group Heuristic" partitions the set of products into G subsets such that all products belonging to one of the subsets

have the same cycle time. Once the subsets are defined, the problem is reduced to one of determining group cycle times rather than product cycle times. The heuristic is described in an IAE research report (Boctor, 1981).

Integer programming solutions to the above problem have not been successful for the numbers of products typically encountered in practice. Therefore, several other heuristic procedures have been developed (Elmaghraby, 1978). Boctor has recently compared six such procedures using an experiment in which 270 simulated problems are successively solved. Six to 10 products are scheduled on the same machine. The primary measure of effectiveness of each procedure is taken to be the percentage increase in cost of its solution over a certain lower bound on cost. While the study perhaps involves an unrealistically small number of products, Boctor has some interesting conclusions about the relative efficiency of the various heuristics involved in his experiment. Although none of the solution procedures tested performed best on all 270 problems, Boctor says that the G-group heuristic produced the best schedules most often, and it exhibited the lowest average increase above the lower cost bound--about 1%. A procedure developed by Haessler and Hogue was second best in terms of average increase in cost, but it took about 30 times longer to compute than the G-group heuristic.

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D. R. Barr

MATERIAL SCIENCES

FIBER COMPOSITE MATERIALS IN THE UK

This the first of a series of articles reporting research on fiber composite materials in the UK. The articles are based on visits to 15 research establishments made during January and February 1983. The range of activities summarized here provides a fair cross-section of current research at the Univ. of Surrey and Cambridge.

Univ. of Surrey

The Univ. of Surrey has done extensive research in fiber composites for many years. Dr. A. Kelly, FRS, is well known for his pioneering work in continuous and discontinuous fiber reinforced plastics and metals. Since becoming the vice chancellor of the university in 1975, Kelly has maintained active interests in research on composite materials. Lately, Kelly has served as the editor for the fiber composite material section of the *Encyclopedia of Materials Science* (Pergamon Press) and as co-editor, with S.T. Mileiko, of *Fabrication of Composite Materials* (North-Holland). Both works are due for publication soon and should be valuable additions to the literature on composites.

The Fibers and Composite Materials Research Group at Surrey operates within the Department of Metallurgy and Materials Technology. Research is in progress on several related projects sponsored by the Science and Engineering Research Council (SERC), government departments, and private industry. The group is supervised by Prof. J.E. Bailey, M.G. Bader, and Dr. F.R. Jones; there are 12 research officers and students. The main activity of the group has been in experimental micromechanics of fiber reinforced materials. Most work has been on glass and carbon-fiber reinforced plastics (GRP and CFRP), but recently significant research has started on metal matrix systems.

The main activities cover seven projects. First, the study of micromechanics of failure in GRP and CFRP laminates is supervised by Bader and sponsored by the Ministry of Defence (Royal Aircraft Establishment [RAE]). The aim of the work has been to evaluate the effect of constitutional and geometric variables on the mechanisms of damage, degradation, and failure in composite laminates. The laminates are manufactured from a commercial unidirectional material preimpregnated by autoclave molding or by conventional wet lay-up techniques and then subjected to a comprehensive program of mechanical testing, which includes fatigue and environmental exposure.

Having established the basic damage mechanisms and the damage sequence under both monotonic and cyclic loading, the

program is now directed toward a study of damage accumulation and residual strength under complex fatigue loading conditions. The program also includes an evaluation of the effects of the molding and curing schedule on mechanical performance. It has been shown that micro-damage occurs at strains well below those required to initiate cracking in the transverse ply (~0.3%) when laminates are loaded monotonically in tension. Under cyclic strain, such damage will develop into transverse cracks and delamination--again, at a cyclic strain amplitude of less than ~0.5%. Damage initiated by occasional high strain excursions will propagate on continued exposure to lower strain amplitude cycling.

The second project--on the strength of mixed fiber hybrid-composite systems--is also supervised by Bader and is sponsored by the SERC and the Ministry of Defence (RAE). Composites containing more than one type of fiber are of interest for several reasons. Very expensive fibers can be used more economically in hybrids, properties optimized, and materials "tailor made" for specific applications. There is also the suggestion that hybrid combinations may actually achieve a higher level of some properties than a simple proportioning rule would indicate. Hybrid laminates containing carbon, glass, and Kevlar® fibers in various combinations are being tested. The major variables are the relative fractions of the two-fiber species and the state of dispersion. The nature of the hybrid effect has been determined and an extensive study made of the relationship between the strength of single fibers and that of "bundles" or larger aggregates.

In the current program Bader has tested a single batch of high strength carbon fiber (Celion 1000) as single fibers at various gauge lengths, unimpregnated and impregnated bundles of 1,000, 3,000, and 9,000 filaments and glass-carbon hybrids containing 1,000-, 3,000- and 9,000-filament bundles. It has been shown that a Weibull model can be applied to the behavior of the single fibers, which have a Weibull shape parameter of about 7. The dry and impregnated bundles have a shape parameter approaching 20, and the hybrid bundles approach 30. The strength of the carbon bundle in hybrid form is significantly higher than that of unhybridized bundles of similar fiber count and gauge length. Work is proceeding on the strength of controlled arrays of carbon bundles in the hybrid system.

The third project--on the effect of resin structure and properties on the internal stress level and microcracking behavior of glass reinforced polyester laminates--is supervised by Jones and sponsored by SERC's Polymer Engineering Directorate. It has been found that the thermal strains in polyester laminates are much higher than the equivalent laminate from epoxy resin. The laminate and resin variables are being studied so that the origin of the strains, which seriously affect the mechanical properties and lifetime of the laminates, can be identified. Improved resin-laminate technology is the ultimate aim.

The fourth project--studying the environmental stress corrosion of glass fiber reinforced epoxy composites--is conducted by Bailey and Jones and is sponsored by SERC. The microstructural factors responsible for the rapid and catastrophic failure of the load bearing plies in the GRP have been identified. The research is now concerned with: (1) the laminate properties responsible for differences in the behavior of the same glass fibers in different resins, and (2) methods of determining the properties of stress corrosion cracks--their growth rate and stress intensity, for example.

Bailey and Jones are examining the effect of debonded interfaces on the stress corrosion of such laminates. The chemistry associated with a change in the failure mechanism on application of a tensile stress is also being examined. The synergism between stress and the environment has been well established, but these effects also lead to unusual failure phenomena. Bailey and Jones are now studying the factors responsible for the catastrophic failure of the load bearing fibers at applied strains as low as 0.05%.

The fifth project--on mechanical transverse impact damage in filament wound GRP tubes--is conducted by Bader under the sponsorship of the Ministry of Defence (Royal Armament Research and Development Establishment [RARDE]). It is well known that high performance, filament wound tubes are often subject to various forms of damage, principally by mishandling. The aim of Bader's work is to determine the influence of the tube's construction variables (e.g., winding angle) on its susceptibility to damage, and to assess the significance of various levels of damage in terms of the required performance characteristics of the laminate. The basic damage mechanisms have been identified for a variety of winding angles, and a finite element model has been developed to

represent the deformation pattern. Efforts are now concentrated on refining the model and correlating it with observed deformation and damage patterns so that it can be used to design the tubes as well as possible.

The sixth project is a toughness and strength study of fiber filled thermoplastics supervised by Bader and sponsored by SERC and ICI. Thermoplastics are a class of easily processed materials that are attractive for high-rate production of many engineering components. However, the usefulness of thermoplastics is limited by low stiffness and relatively low resistance to elevated temperature. These problems can be solved by incorporating mineral particulate or fibrous fillers. It has been found that glass fibers 10 μm in diameter and 100- to 500-μm long provide significantly more stiffness, improve the strength, and dramatically improve the dimensional stability of many thermoplastic materials. There is, however, a penalty: greater difficulty in processing and a tendency toward brittleness.

The principal objective of the research is to study how the toughness and strength of typical filled thermoplastics (glass fiber filled nylon) are controlled by structural and processing variables--for instance, the effects of varying the amount of fiber added, the diameter and length of the individual filaments, the type of bond between the matrix (nylon) and the glass surface, and the orientation distribution of the filler particles. A complex set of interacting effects is involved; the goal is to isolate individual effects and evaluate them by carefully designed model experiments.

It has been shown that the Charpy impact energy increases with the fiber content, and that the rubber-toughened nylons significantly increase the impact performance, but with a small loss of stiffness. Attempts to modify the toughness by altering the fiber interface have shown that lowering the interface strength reduces the stiffness, strength, ductility, and toughness. There appears to be no merit in pursuing the work to increase energy absorption due to fiber pull-out. It has also been shown that conventional tests (like the Charpy), which involve total separation of the test piece on fracture, do not show the same trends as other tests in which fracture is merely initiated. Fracture appears to initiate just as easily in many of the apparently "tougher" materials. Work is now concentrated on alternative testing techniques that may yield data of more significance for design purposes.

The seventh project, which is on alumina-fiber-reinforced metal matrix composites, is conducted by Bader and Dr. T.W. Clyne, and is sponsored by ICI's Mond Division. The aim of the work is to exploit the cheap discontinuous alumina "Saffil" fibers available from ICI. The fibers are of much smaller diameter (3 to 5 μm) than the alternative continuous alumina fibers and are manufactured in the form of a staple mat. Initial experiments have impregnated the fibers with suitable metals using, when possible, the liquid metal route.

Bader and Clyne have established that a range of commercially available aluminium alloys will adequately wet the fibers. Composites containing up to 20% by volume of the fiber have been produced by stir blending and by pressure infiltration techniques. Initial evaluation has indicated that, compared with the unreinforced alloys, the composites have greatly improved hardness, wear resistance, and elevated temperature performance.

Univ. of Cambridge

Fiber composite material research at Cambridge Univ. is conducted primarily in the Engineering Department by Prof. M.F. Ashby, FRS, and Dr. P.W.R. Beaumont. Ashby's current research includes material resources, grain boundary structure, creep of polycrystalline solids, deformation-mechanism diagrams, sintering processes, mechanics of cellular materials, compressive fracture of brittle solids, and mechanics of ice. Beaumont's research is in failure processes in polymer and fiber composites, fatigue damage of fiber composites, environmental degradation of fiber composites, and direct observation of dynamic fracture of solids.

Composite-related projects include the following: (1) a damage-accumulation approach to the fatigue of composites, (2) correlations for the fracture of composite materials, and (3) the use of fracture maps in a failure analysis of fiber composites.

Damage Accumulation. A damage accumulation approach has potential because it can predict fatigue life under varying load histories or residual life after a known earlier history. The basis of the work is that damage accumulates within a composite material during fatigue loading. The damage may have several components, such as fiber breakage, matrix cracking, and fiber-

matrix interface debonding. Ashby and Beaumont propose that the fatigue damage be measured by the variable they call D. Cyclic loading makes damage increase from the initial value D_i to the final value D_f, at which fast fracture occurs either by the aggregation and linking of general damage, or by the propagation of a single crack.

The damage accumulation in composites under fatigue is described by a damage function, $f(\Delta\sigma,D)$, which depends on cyclic stress amplitude, $\Delta\sigma$, and on the current value of D. Then

$$\frac{dD}{dN} = f(\Delta\sigma,D) \text{ or } dN = \frac{dD}{f(\Delta\sigma,D)}.$$

This can be integrated to give the life, N_f, when D changes from D_i to D_f. Of course, the difficulty of such an approach is that the damage function, f, is not readily known. But the damage affects other properties. If, for example, the damage is made up of cracks, then their presence lowers the elastic moduli of the sample, and the modulus can be used to monitor damage.

To determine the damage function, Ashby and Beaumont have used the data for the change of elastic stiffness with the number of loading cycles, and a simple theoretical relation between the elastic stiffness and D. It seems that the predictability of such a damage-accumulation approach to fatigue life hinges on the identification of the proper damage function. When damage occurs in forms other than cracks transverse to the fiber direction, and when there are interactions among the different types of damages, the task becomes much more difficult.

Correlations. Beaumont and a research student, J.K. Wells, have provided some useful insights with correlations for the fracture of composite materials. Beaumont and Wells collected a large body of existing data for both the notched and unnotched strength of fiber composites and presented the information in "master plots." The materials include carbon, glass, and Kevlar 49 fibers in epoxy or polyester matrices. A total of 250 results for 14 different laminate constructions were considered. Test geometries included central circular holes, central slits, and inclined slits.

When data for the normalized fracture strength of composites (that is, fracture strength of a sample containing a crack or notch of length a, divided by the unnotched strength) are plotted against crack length, two regimes of behavior appear. When cracks are short (a<2 mm), the composite fails by a general-damage mechanism at a stress independent of the initial crack length. But when cracks are longer (a>2 mm), the composite fails by the propagation of the crack or notch, with little or no general damage, and at a stress that depends on $a^{-1/2}$.

By general damage, Beaumont and Wells mean the accumulation of broken fibers until the probability of adjacent breaks reaches a critical value, at which failure occurs. Single crack failure occurs when the crack is long enough to focus all the damage at the crack tip and the crack becomes unstable. The level of stress at which crack instability occurs can be calculated using the standard methods of fracture mechanics. Beaumont and Wells plotted the fracture strength data versus notch length and determined the fracture toughness of the composites in the regime. The results show a remarkable consistency; each composite for which data were available had a ratio of fracture toughness, K_{IC}, to unnotched strength, σ_u, in the range

$$\frac{K_{IC}}{\sigma_u} = 0.07 \pm 0.02 \text{ m}^{1/2}.$$

Beaumont and Wells indicate that their approach is different from the "point stress" and "average stress" criteria other investigators have developed to predict fracture strength of composites. The main feature of previous criteria is that by choosing a fixed critical distance for stress distribution in front of a notch, one can obtain an apparent fracture toughness that fails when the crack length is shorter than the critical distance. However, Beaumont and Well's interpretation is different: the reduction is due to a change from a single-crack mode of failure to one associated with general damage.

Fracture Maps. Beaumont and Wells have recently completed a study of the use of fracture maps for analyzing the failure of fiber composites. The basic idea is similar to the deformation-mechanism map concept developed by Ashby for metallic materials. Beaumont and Wells first examined the energy absorption mechanisms in the failure of unidirectional fiber composites. For energy

absorption, they identified in the literature six models, which involve 15 parameters. Typical energy absorption mechanisms include fiber fracture, matrix fracture, interfacial debonding, and fiber pull-out. Major parameters are the strength and elastic properties of fiber and matrix, fiber volume fraction, fiber (or bundle) diameter, and fiber-matrix misfit strain due to chain shrinkage.

The effect of the complex interactions of material properties on composite energy absorption, or "toughness," cannot be seen easily from a set of mathematical equations. Beaumont and Wells therefore presented the fracture toughness in the form of a map, on which one can clearly see the effect of two simultaneously varying material properties. For example, contours of constant toughness can be presented on a map with fiber strength and fiber-matrix misfit strain as variables. On the same map, contours of constant fiber pull-out length and interface debond length can be superposed.

Beaumont and Wells have concluded that only six of the 15 parameters strongly affect toughness. Results from fracture maps have been obtained only for unidirectional continuous fiber composites under static loading and hygrothermal effects. Maps could provide, for instance, information on the key factors relevant to the processing of fiber composites when better toughness is desirable. The complexity of the approach undoubtedly will increase when laminates are considered. It is also understood that the relation between toughness and material property is complex. The change of one parameter--matrix elastic stiffness, for example--could also affect other parameters, such as interfacial properties. Some correlations between theory and experiments have been made by Beaumont and Wells.

T.-W. Chou

MATERIALS RESEARCH AT LIVERPOOL UNIV.

There are now 49 research projects in materials science at Liverpool Univ., including investigations of crystal defects and irradiation damage, surfaces and interfaces, oxidation and diffusion, surface heat treatment, deformation and fracture of metals and alloys, biomaterials, and polymers and polymer composites. Sixteen of the projects are polymer related. (See also *ESN* 35-8:307 [1981].)

Prof. B.L. Eyre, Head of the Department of Metallurgy and Materials Science, has succeeded Prof. Derek Hull who is now fully involved in research and teaching. Among the faculty, D.J. Bacon is reader, R.C. Pond and J.B. Shortall are senior lecturers, and A.G. Gibson, F.W. Noble, N. Swindells, and G.J. Tatlock are lecturers. The department includes 19 research fellows, associates, and assistants; 24 research students; and three senior experimental officers for the electron microscope, x-ray, and microprobe equipment.

Major facilities available for the total projects are the ICL 1906S and IBM 4341 computers; five electron microscopes; two x-ray generators; an emission spectrometer; mechanical property equipment, including a multiaxial servohydraulic machine for combined stress tests and a high-speed test facility allowing a displacement rate of 4 m/s over a distance of 30 cm; a Wolfson Plasma Processing Unit for surface hardening; and an SKM76-110 injection molding machine for processing thermoplastic and thermosetting polymers. A new development is that small computers are a dedicated part of the various experimental units; for example, microprocessors are linked to the energy dispersive analysis of x-rays (EDAX) unit on the Phillips 501 and EM400 scanning and transmission electron microscopes, the Kontron Videoplan image analyzer on the Polyvac F1000 Emission Spectrometer and the JXA 50A electron microprobe, and the control and measurements systems for the mechanical properties equipment.

Fracture

F.F. Noble and Eyre are studying sources of embrittlement and fracturing of a number of steel materials--especially the temper embrittlement of 2.25 % chromium-molybdenum steels, the ductile fracture of 316 stainless steel, and the fracturing of A533B (PWR) nuclear reactor steel. A new aspect of the temper embrittlement studies is the use of the Phillips EM400T electron microscope to identify micro precipitates of M_2C and M_6C carbides and to investigate the role of sulfur, phosphorus, antimony, and tin. The indication is that elemental analyses and spatial resolution can be achieved over lengths of 5 nm on particles extracted on films. Such high resolution studies are limited to some extent by the nature of the extraction process used.

The 2 chromium-1 molybdenum steel used for pressure vessels and heat

exchangers and the nickel-chromium steels for steam turbine components are susceptible to embrittlement on tempering. Fatigue fracturing of 316 stainless steel relates to its use in medical prostheses. The microstructural distribution of cracks and their linking in the necked region of ductile tensile specimens is being studied. The separate effects of inclusions versus precipitates formed on aging are being investigated for the ductile fracturing of A533B steel. The fracture stress dependence on grain boundary oxygen content has been determined for molybdenum bicrystals containing a bulk concentration of 6 atomic parts per million of oxygen.

Irradiation Damage

D.J. Bacon and Eyre have complementary interests--the computer simulation of crystal defects and the electron microscope observation of irradiation damage structures, respectively. The atomic structure of defects within a simulated crystal of 9,000 atoms is computed with a program called XLITE. Stacking fault energies have been computed for a model hexagonal close-packed metal. The equilibrium shapes of dislocations bowed between impenetrable obstacles have been computed for iron to specify the character of Orowan strengthening. Polyethylene crystals have been simulated with defects and subjected to applied stresses.

Irradiation damage studies for dimensional changes and failure of metal components of nuclear reactors have been a continuing topic of research at Liverpool. Recently theoretical and experimental studies for fusion reactor materials have been started. The first wall and blanket structures in fusion reactors have to withstand very high neutron doses. Transmutation reactions and ion bombardment damage are of interest. In association with the Atomic Energy Research Establishment (AERE), Harwell, researchers at Liverpool have studied krypton, argon, and tungsten ion bombardment of ruthenium. Vacancy loops as small as 1-nm diameter have been identified by their diffraction contrast in the electron microscope. Computer simulation of the diffraction contrast has been a valuable tool in identifying such small defect clusters. The atomic sequence of collisions, replacement processes, and defect aggregation are being studied.

Interfaces

Before coming to Liverpool, R.C. Pond was at Bristol and Oxford studying the structure of grain boundaries both theoretically and experimentally. Computer simulation and transmission electron microscope observations have been made of grain boundary structures in aluminum. Pond and Garcia-Garcia (1981) reported the observation of deformation twinning in aluminum at the tips of cracks produced by electropolishing thin specimens for electron microscope observations. The identification was based on obtaining diffraction images from the twinned volume 10-nm thick and the surrounding matrix material, and on identifying the twinning dislocations at the tail end of a pile-up in the interface.

Pond is now looking into the structure of twins and grain boundaries in diamond cubic lattice structures, particularly silicon, and has become interested in the general theory for symmetry properties of interfaces in more complex materials, including polar structures. An exciting development has been his model for the $\{211\}$ lateral twin boundary in silicon shown in Figure 1 (Pond, 1982). The model involves a translation of one crystal by a distance of approximately 0.12 nm relative to the other; the components of translation are both parallel and perpendicular to the twin interface. The model is important for consideration of the electrical properties of boundaries (and dislocations) in semiconductors.

Pond and Hull are interested in interfaces from a biomaterials viewpoint. Besides research on the microstructures of dental amalgams and the chemical corrosion of metal prostheses, there has been work on the compatibility

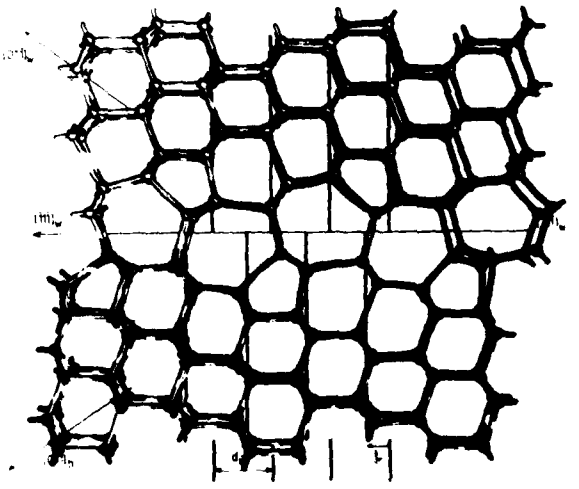

Figure 1. Model of lateral $(21\bar{1})$ twin boundary exhibiting no dangling bonds in the diamond cubic lattice.

of synthetic polymers and surrounding tissues. Transmission electron microscope observations are being made of implanted polymer fibers in animal tissue. Beahan and Hull (1982) reported optical, scanning, and transmission electron microscope observations of interface morphologies between a polyurethane arterial prosthesis and living tissue. Ingrowth by the tissue is an important concern for eventual encapsulation of the implant by connective tissue.

Oxidation

G.J. Tatlock and N. Swindells are studying oxidation processes on the ultramicro and micro scales. Tatlock pursues the subject mainly by electron microscope methods. Projects include EDAX for the oxidation and hot corrosion of nickel-based superalloys containing rare earth and platinum group additions (Tatlock and Hurd, 1982), the oxidation resistance of "Fecralloy" steels, internal oxidation processes, and sulphidation studies. Tatlock is also interested in the electron microscope study of intercalation in layered materials.

Swindells has been working for some time on the development and use of a computer-controlled electron probe microanalyzer for chemical analysis of micron-sized constituents and for multi-element diffusion studies. Diffusion is being measured in ternary single- and two-phase chromium-aluminum and cobalt-chromium-aluminum alloy systems for gas turbine engines. In a laboratory simulation of the chemical environment, Swindells is studying the oxidation and corrosion of coated superalloys and overlay coatings on various gas turbine alloys. The project has been in collaboration with the COST-50 program (*ESN* 37-1:21 [1983]). Ternary systems of silicon, titanium, or platinum with nickel and aluminum are of interest. The Phillips EM400 microscope is used in scanning transmission (STEM) to examine with x-ray analysis segregation effects at the 10-nm level. Work on diffusion is in collaboration with the Univ. of Eindhoven and on oxidation with Johnson Matthey Research and the AERE, Harwell.

Polymers

Hull, A.G. Gibson, and J.B. Shortall are pursuing a variety of polymer-related interests. Research on the deformation and fracture of polymers began at Liverpool in 1967. Gibson is investigating the injection molding of polyester compounds--which have certain cost, thermal stability, and creep behavior advantages over thermoplastic polymeric materials--for use in automobile components. Shortall is investigating cellular or foamed plastic materials. Glass fiber reinforcement of polyurethane foams, polyester molding compounds, and reinforced reaction injection molding are being studied by Shortall and Gibson. For automotive, pipe, and pressure vessel applications, Hull is studying the properties of filament-wound structures made of polyester molding and reinforced reaction injection molding materials. Ford Motor Company, Pilkington Brothers and the Science Research Council have supported work on the development of lightweight materials of reasonable energy-absorbing capacity, particularly at high strain rates. The composites work has been described by Hull (1982) and is to be up-dated in a forthcoming *ESN* article, by T.-W. Chou of the Univ. of Delaware.

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R.W. Armstrong

PHYSICS

LIGHTNING VULNERABILITY STUDIES AT THE CULHAM LABORATORY

Aircraft have become more vulnerable to lightning strikes because of

recent trends in design--thinner metal components, fiber composite structures and sophisticated solid-state circuitry, for example. At Culham Laboratory (Abington, Oxfordshire, UK), the Culham Lightning Studies Unit (CLSU) was created in 1972 to devise test techniques leading to improved protection measures for the UK and European aerospace industries. CLSU's director, B.J.C. Burrows, recently described the unit's research program devoted to vulnerability testing of aircraft, ships, and ground-based communications systems, and provided an extended tour of the experimental facilities.

The Culham Laboratory is best known as the home of JET, the Joint European Torus (a large tokamak fusion experiment supported by the members of the European Economic Community) and many other magnetically confined plasma experiments. The laboratory was chosen for the lightning studies unit because the hardware and pulsed-power expertise were already on site, computer programs for field plotting were in place, and plasma physics personnel were expert in electrical discharge behavior.

To accomplish its objectives, the CLSU carries out a program of applied research on lightning strikes and publishes guides to lightning vulnerability testing and safeguarding. The unit provides results of the research to UK and European aircraft and component manufacturers. Manufacturers can also hire CLSU's test facility for their own experiments and consult Culham staff on design considerations for components that are likely to be damaged. The unit organizes international symposia to address lightning phenomena and vulnerability issues.

In the above capacities, the CLSU is unique in Europe. CLSU and US agencies have cooperated closely in establishing international standards for testing. Current CLSU programs include studies and tests for the UK, US, and Scandinavia.

Lightning Phenomena

The generally accepted distribution of electric charge in a typical thundercloud (Figure 1) consists of a large positively charged ice crystal region, P, toward the top of the cloud; a large negatively charged water droplet region, N, in the middle; and a small positively charged region, p, at the base. There are three main types of cloud discharges: intracloud P-N and N-p discharges in the upper and lower regions of the cloud, intercloud flashes from a charge center within one cloud to the opposite charge center within another,

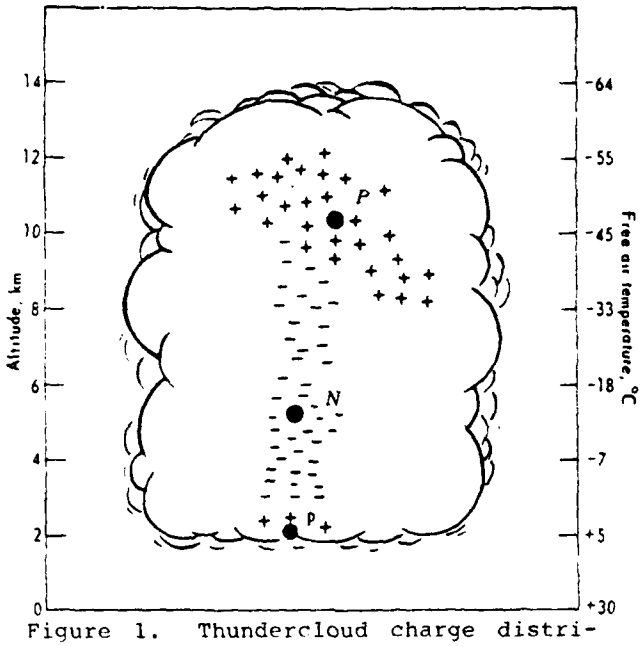

Figure 1. Thundercloud charge distribution.

and flashes from either the N or P region to ground occur.

Although aircraft frequently contact intracloud flashes, the damage suggests that severe ground flashes represent the greatest threat. Most lightning current measurements have been associated with ground flashes, and such data are used to establish vulnerability testing requirements.

The breakdown process is thought to begin in the N-p region, from which a negatively charged column is propagated to ground or another charge center. The column, called a stepped leader, advances in a series of rapid discontinuous steps about 50-m long and separated by pauses of about 50 μs. The luminous diameter of the stepped leader is between 1 and 10 m, with about 100 A flowing in a small diameter core.

Once the stepped leader reaches ground (or an upward leader from the earth), either positive or negative ground flashes can occur. A positive ground flash usually consists of one stroke and occurs less frequently than the negative flash. However, a positive flash often has a higher energy content. A negative flash is characterized by several strokes of high peak current, with a low amplitude but long duration continuing current between some of the discharges (Figure 2).

The high peak current phase has a typical magnitude of 10 to 30 kA. Higher currents are possible, though less probable; a peak current of 200 kA

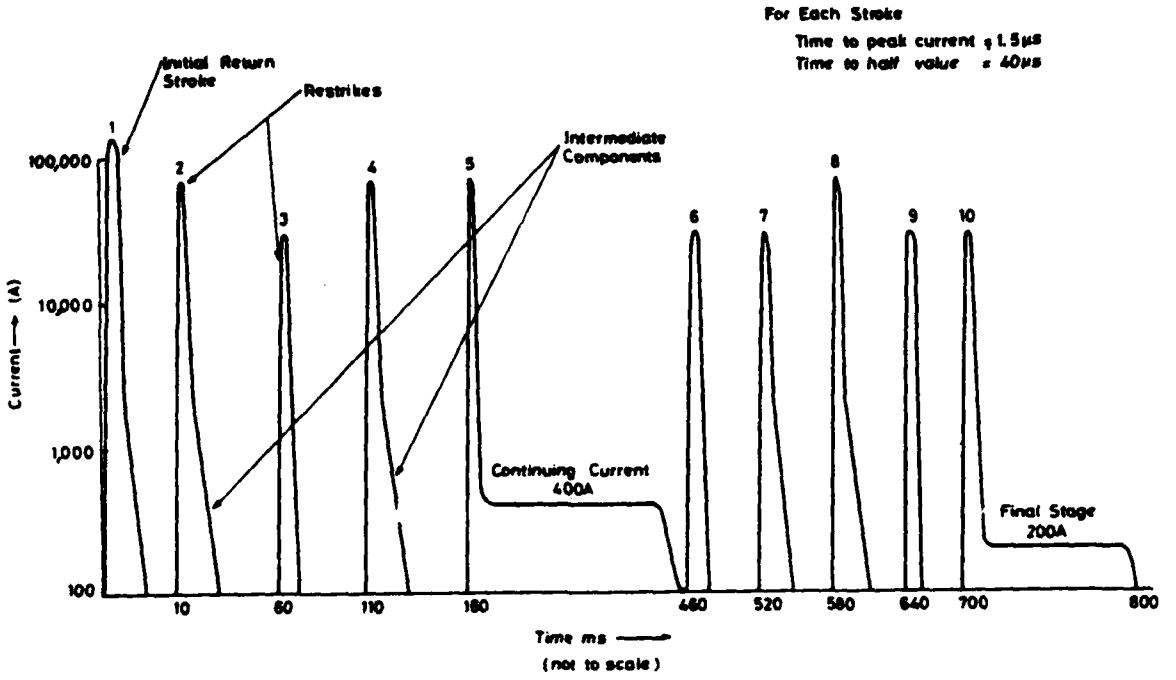

Figure 2. A severe negative lightning flash current waveform.

is exceeded in only 0.5% of all flashes. The current in the initial return stroke has a fast rate of rise, typically 10 to 20 kA/μs. After reaching maximum, the current decays to half its peak value in about 50 μs. In a typical negative lightning flash, several high current strokes follow the first return stroke as different charge pockets in the cloud are fed into the lightning channel. The peak amplitude of the restrikes is about half that of the first return stroke, but often with a greater rate of rise of current (over 100 kA/μs has been measured).

After the initial fast decay from peak current, some strokes maintain for several milliseconds a few-kiloampere current flow, which is called the intermediate current. The total charge transferred by the high current strokes is usually a few coulombs. However, between some of the strokes or after the last stroke, a continuing current phase exists for 100 to 800 ms, when 100 to 400 A may flow. A severe discharge transfers about 200 C of charge during the continuing current phase.

The current waveforms of the lightning flashes are most important in deciding what damage will be sustained and what tests and facilities are necessary to simulate the same damage in the laboratory. The important parameters of the current waveform are peak current, rate of rise, total discharge duration, the total charge transferred, and the action integral (the time integral of the current squared). The units of the action integral are A^2s or, alternatively, joules per ohm because it is proportional to the electrical energy dissipated in a given resistance.

Different types of damage are associated with the various phases of a stroke. Laboratory simulation is designed to simulate only a few aspects of the complex behavior. Essential features of each phase are contained in an internationally agreed upon equivalent test lightning waveform shown in Figure 3. For testing airworthiness, it was decided that the four-component current waveform shown with the parameters in Table 1 give an effect equivalent to that produced by natural lightning. Additional requirements concerning the rate of rise for restrikes have been formulated for electromagnetically induced voltage tests.

The Interaction of Lightning With Aircraft

As a stepped leader approaches an aircraft, the electric fields at the

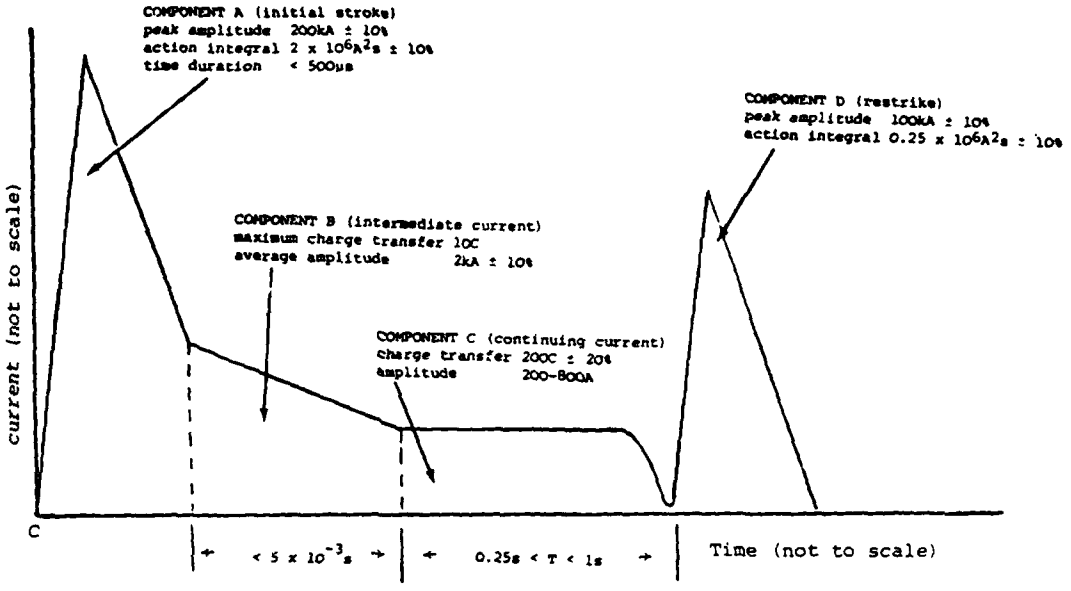

Figure 3. Idealized current waveform for testing.

surface give rise to streamer discharges, which propagate away from the aircraft until one contacts the approaching stepped leader (Figure 4). Propagation of the stepped leader continues from other aircraft extremities until one of the branches reaches the ground or another charge center. The entry and exit points of the discharge are called attachment points. Typically, the initial attachment points are in the high-field extremities of the aircraft--such as the nose, wing tip, fin and tail tips, protruding aerials, engine pods, and propeller blades.

The lightning channel is effectively stationary in space, with the moving aircraft becoming part of it. Thus, with respect to the aircraft, the lightning channel is swept back over the surface. However, the sweep back does not occur smoothly. The arc remains at a forward attachment point and is stretched behind and parallel to the surface until the voltage across the air gap and any insulating coating is sufficient for breakdown at a back attachment point. The attachment point, dwelling at various surface locations for differing periods of time, executes a skipping action along the swept path. Therefore, parts of the aircraft that would not otherwise be targets for attachment may be involved as a result of the rearward sweeping action. If an initial attachment point is a trailing edge, it may carry the full current associated with the flash for its duration. High peak current restrikes with intermediate current components and continuing currents may be swept. Restrikes typically produce reattachment of the arc at a new point.

When simulated by laboratory testing, the effects on an aircraft must be divided into two groups because of the limitations of laboratory facilities. Group 1 items cover effects such as burning, eroding, blasting, and structural deformation. These are associated with high currents and sustained discharges but are not sensitive to the current rate of rise. Group 1 effects are local in that they depend on the interaction of the lightning with a small region of the aircraft. Testing, then, often can be conducted on individual components.

Group 2 effects result from the lightning current's electromagnetic field and its interaction with the electrical apparatus in the aircraft. The major threats are transient voltages induced in wiring and sparking--effects associated with high peak current and high rate of change of current. Group 2 effects depend on the response of the entire aircraft to current flow, the electromagnetic pulse, and even the distribution of charge and current in the surrounding atmosphere. Testing must often be conducted on the entire aircraft, with current return paths adjusted to simulate the atmospheric

Table 1

Components for Airworthiness

Component	Parameter	Value
High current component A	Peak current	200 kA
	Action integral	2×10^6 A^2s
	Pulse length	< 500 μs
	Rise time	< 25 μs
Intermediate current component B	Average amplitude	2 kA
	Charge transfer	10 C
Continuing current component C	Amplitude	200-800 A
	Charge transfer	200 C
Restrike component D	Peak amplitude	100 kA
	Action integral	0.25×10^6 A^2s
	Pulse length	< 500 μs

environment even when the vulnerability of an individual component is to be tested.

The various threat modes occur on different parts of the aircraft and are usually associated with individual components of the stroke and a few of its parameters. The following are the most important threats.

- Burning and eroding. The burning and eroding of a metal surface depends primarily on the charge transferred to it. Therefore, the continuing current phase of a lightning flash can cause such damage. The most severe damage occurs when the lightning channel dwells at one point on the aircraft for the entire phase, causing holes of up to several centimeters in diameter.
- Disruptive pressure. The high peak current phase of the lightning flash transfers a large quantity of energy in a short time. The energy transfer, proportional to the action integral, can result in fast thermal vaporization of material. If this occurs in a confined area, a pressure high enough to cause structural damage may be created. Such a mechanism applies to composite panels and major nonmetallic components such as radomes.
- Magnetic force. During the high peak current phase, the flow of current through sharp bends of the aircraft structure can cause large magnetic forces to be produced. Such forces can twist, rip, or distort structures away from rivets, screws, and other fasteners. The magnetic forces are proportional to the square of the instantaneous lightning currents, so the impulse is proportional to the action integral.
- Ignition hazards. Fuel vapors and other combustibles may be ignited in several ways by a lightning flash. The current can burn through thin metallic skins over fuel tanks or produce a local hot spot which might cause ignition. The hazard depends primarily on the action integral. The flow of current through a poorly bonded aircraft structure can cause sparking. The degree of sparking is related to the local peak current density, the rate of change of current, and the action integral. A transient voltage induced by the lightning current into electrical wiring within the fuel tank can cause insulation failure and sparking. The effect depends on the current maximum and rate of change. During the prestrike phase, high electrical stresses around the aircraft produce streamers. If streamers occur near a fuel vent, there is some evidence to suggest that ignition can occur.
- Mechanical shock. The air channel through which the lightning flash propagates is rapidly heated to approximately 30,000°C. The resulting

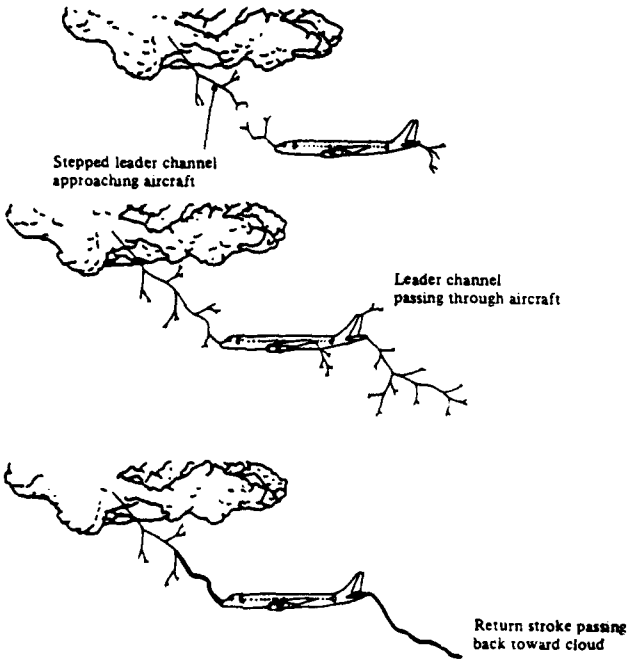

Figure 4. Lightning flash striking an aircraft.

shock wave impinging upon a surface can cause mechanical damage.

- Induced voltages in wiring. The metallic structure of the aircraft does not provide a perfect electromagnetic shield. The magnetic fields associated with the lightning current can then penetrate the aircraft in two ways. The flux can penetrate directly through apertures or nonmetallic sections to produce direct flux-coupled voltages. The induced voltage is proportional to the rate of change of current. The system response depends on the voltage-time characteristic, the second derivative of the current, and for digital electronic systems, the number of restrikes and the interval between them.

The field can also diffuse through the metallic skin of the aircraft and produce a voltage in electrical circuits or set up electrical stress between circuits and the airframe. Because of the skin effect, the induced voltage due to diffusion through a metal surface exhibits a time delay relative to the current pulse. The important parameters for field diffusion are the peak current density, the shape and duration of the pulse, and characteristics of the metallic skin. Direct coupling through apertures and nonmetal sections is likely to produce larger voltage transients with a higher frequency content than does diffusive coupling.

- Sparking. Currents rising in about 5 μs or less flow in the top surface of aluminum alloy to a depth of only 0.5 mm. If the surfaces of two plates forming a joint have a thin insulating coating, the current has to take an inductive roundabout path that induces voltages proportional to the derivative of the current, di/dt, between the two plates. Sparking is initiated by high di/dt and may be sustained by later intermediate currents. Although it can have low resistance to steady state current flow, a bond might break down at the high frequencies associated with a lightning strike.

The CLSU Experimental Program

CLSU's experimental facility consists of three capacitor banks, a motor generator set, a battery bank, and electrostatic high voltage generators in an experimental bay suitable for large structure tests.

The intermediate capacitor bank (600 kJ, 20 kV) produces a 100-A to 50-kA pulse with charge transfer up to 500 C. The device provides high action and long duration currents to simulate the Group 1 effects associated with the intermediate and continuing current phases (components B and C). The capacitor bank usually discharges via ignitrons into an air core, aluminum winding with an inductance of 0.7 H that acts as an intermediate store of electrical energy. An inductive store is needed to simulate the electrical

characteristics of the long lightning discharge channel. (When capacitors or batteries are used to sustain an arc, the constant voltage characteristic causes the arc to quench when its impedance rises. With increasing impedance, an inductively sustained arc will experience a voltage rise associated with the constant current character of the source.) The inductor can be tapped at various points on the winding for different pulse characteristics. Current rise and fall characteristics are further controlled by command triggered ignition switching.

Air arcs are initiated with the high voltage resulting from the crowbarring of the charged inductor. Long arcs (up to 5 m) are established by the vaporization and breakdown of fine fuse wires. To study burning and erosion, a vertical arc is established between a spherical metal electrode and a plate to be tested. The test rig has several special features for vulnerability studies. The spherical (top) electrode is coated with an epoxy or ceramic insulator on the hemisphere facing the plate so that the arc is drawn from the top hemisphere to the plate below. Thus there is no contamination of the arc by metal vapor from the electrode (not present in the threat environment). The return current path in the test rig is symmetric to eliminate magnetic forces that can cause the arc to wander and lead to instability.

For swept stroke testing, a rail electrode and parallel test specimen are used. The arc is driven across the component under study by an applied transverse magnetic field. The inductive store is crucial for swept stroke simulation because the voltage can fluctuate widely as the arc skips between attachment points.

In addition to instrumentation for electrical measurements, there are light sensitive diodes and equipment for high speed cine photography. The devices are used to determine the instant of skin puncture and the motion of electrode plasma.

The fast capacitor bank (140 kJ, 100 kV) is designed to simulate the first return stroke of a severe lightning discharge (component A of the test waveform). The bank generates a 200-kA pulse with a 5- to 15-μs rise time for an action integral of 2 to 3×10^6 A^2s. The system is discharged through high-pressure-gas, field-distortion switches that operate in the 2- to 100-kV regime. The pulse can feed an arc or can be current injected directly into a structure.

Presently, the fast bank is driving current through a drop tank and a Jaguar wing on which it is mounted. CLSU is studying how the return stroke current flows through the structure and how the flow induces internal currents. In addition, the vulnerability to fuel ignition by sparking is being evaluated. Dr. Burrows showed me empty drop tanks that had been tested (the same threat exists in a partially full tank). The front portions of the tanks had been explosively blown away. Though the tanks were made of a fiber composite, each contained a thin metal strip ringing it near the front. Induced high currents rapidly vaporized the strip, thereby producing an overpressure sufficient to blow out the tank.

A complete study of a similar threat to a ship's hull has also been carried out. CLSU tested a ground plate at the bottom of the fiber-epoxy hull of a British Navy vessel. The water in estuaries has impedance high enough to support dielectric breakdown to the metal plate from a lightning stroke into the water. The high field region at the edge of the plate creates arcing at the composite hull-plate-water interface. The plasma overpressure can then puncture the hull. Such triple-point breakdown is sensitive to the surrounding electric field distribution. To insure a proper simulation, a field plotting code was used to determine the three-dimensional potential contours in a water half-space bounded by the plate and hull. For the experiment, the return current path in water was fashioned in the shape of an equipotential. The interior field distribution in the test then corresponded closely to the threat in nature. Calculations indicated that nearby strikes in the sea could lead to 3-MV potential differences appearing between metal parts in glass-fiber hulls. Thus, components such as guard rings for electronic systems might actually increase vulnerability in certain circumstances.

The technique of conforming the test return current path to a free space equipotential surface is also important to aircraft testing of Group 2 effects. The path must be far enough from the fuselage to provide realistic field distributions but close enough to prevent excess inductance from slowing the current rise.

The high rate of rise generator (40 kJ, 1 MV) is used for induced voltage tests on a Hawker-Hunter fuselage with a return current superstructure. The device is a five-stage Marx generator consisting of 0.375-μF, 200-kV capacitors with low inductance gas switching.

The generator provides less than a 1-μs current rise to peak for full threat testing at 10^{11} A/s. The facility has recently been used to determine induced voltages in cables via flux coupling through a carbon fiber composite component of the US Navy's F18 aircraft. The tests were conducted with carbon fiber panels bonded or screwed onto the Hawker-Hunter fuselage in various ways. Full-scale current level tests on a complete aircraft were also undertaken by CLSU for SAAB of Sweden, using a transportable pulse generator. Most recently, the unit has been investigating rapid fluctuations in the current rise associated with the 50-ns round trip transit time of an electromagnetic pulse in the Hawker-Hunter. As the induced voltages are proportional to di/dt, such fast transients can have substantial impact even though they are of low amplitude.

A 600-kV electrostatic generator is used to study the development of coronas around aircraft and to assess dielectric breakdown mechanisms in structures and components. Currently, threats to windscreen assemblies due to static charging by ice particles are being evaluated for a UK component manufacturer. The tests are conducted by creating fine water droplets in a high-speed air expansion nozzle. Electron emission from a high-voltage needle electrode embedded in the spray charges the droplets before they hit the windscreen's surface. The threat is associated with discharges created at the metal dielectric interface on the windscreen perimeter.

CLSU has published two important documents to serve as guides for testing techniques and aircraft design. Both are well written and contain much useful information on the phenomenology and threats of lightning strikes:

J. Phillpot, *Recommended Practice for Lightning Simulation and Testing Techniques for Aircraft*, Culham Laboratory Report CLM-R163 (1977).

B.J.C. Burrows, *Designers Guide to the Installation of Electrical Wiring and Equipment in Aircraft to Minimise Lightning Effects*, Culham Laboratory Report CLM-R212 (1981).

D. Mosher

SPACE SCIENCES

MAX PLANCK INSTITUTE FOR AERONOMY

In the past decade, the Max Planck Institute for Aeronomy (MPAE) has emerged as a leading space research institution. In large measure, the emergence has resulted from the leadership provided since Prof. W. Ian Axford joined MPAE as a director in 1974. The name of the institute is somewhat an anachronism as MPAE has major scientific programs relating to many aspects of the solar system, extending far beyond the upper atmosphere (to which the term aeronomy usually refers).

Axford is a New Zealander who established a distinguished scientific reputation in Canada and the US from 1960 to 1975. His principal appointments in the US were at Cornell Univ. and the Univ. of California, San Diego. Axford is a theoretical physicist with broad interdisciplinary interests that include the ionospheres and magnetospheres of planets, solar physics, the solar wind, cosmic rays, and astrophysics. He has published widely, and one of his articles, co-authored with C.O. Hines, is a landmark in the development of the modern approach to magnetospheric dynamics: "A Unifying Theory of High Latitude Geophysical Phenomona and Geomagnetic Storms," *Canadian Journal of Physics*, 39 (1961), 1433-64. Axford has made fundamental contributions in many areas, including magnetic reconnection, thermospheric dynamics, and the termination of the heliosphere. While editor of the *Journal of Geophysical Research-Space Physics*, the most prestigious journal in the field acquired even greater respectability under his guidance. At professional society meetings and at formal national advisory committee meetings, Axford has been both an incisive critic and a decisive supporter of enterprising and promising efforts. Axford's professional credentials prompted his recruitment to MPAE, and his good judgment, persistence, and charisma led to the rapid development of the institution to its current prominence.

MPAE was formed in 1955 from the merger of the Max Planck Institutes for Ionospheric Research (headed by W. Dieminger) and for the Physics of the Stratosphere (founded by E. Regener and subsequently headed by G. Pfotzer). The merger was primarily administrative, however, and the two institutes remained scientifically distinct. In 1975 Axford introduced the basic reform that led to the current operational structure of MPAE. The research programs of the institute were unified under one management and housed in a single set of buildings. Routine measurements or long-term monitoring activities of the institute were placed at a separate

location and by 1979 had ceased permanently.

Axford's philosophy was for MPAE to engage in scientific projects that were carefully chosen for limited scope and duration, and that could be carried out by the scientific and technical staff of the institute. Deliberate efforts were made to engage more in developing and exploring new points of view and less in precision measurements of established areas. Scientific and technical innovation was encouraged and accomplished. Through implementation of this philosophy, the structure of MPAE became defined by scientific projects of finite duration rather than by rigid departments or divisions. In a rapidly developing field and institution, the structure provided the flexibility to accommodate useful changes in direction and new programs.

In no small measure, MPAE has thrived from Axford's successful recruitment of prominent scholars and his greatly expanded visitors program. Both V.M. Vasyliunas and H. Rosenbauer, also directors of MPAE, were recruited by Axford, as were J. Fejer and many others. The visitors program has two components, each providing an active exchange of ideas and intellectual enrichment to MPAE staff members. Some two dozen visiting scientists from many nations hold appointments at MPAE each year; the terms vary from a few weeks to a year or more. Additional dozens of scientists and other dignitaries visit for shorter periods, often contributing to the active colloquium series or other in-house programs.

MPAE research includes atmospheric and ionospheric physics, planetary magnetospheres, the solar wind, and solar-planetary science in general. Institute members are engaged in experimental, observational, and theoretical research. Scientific studies include ground-based programs, rockets and balloons, and satellite experiments. Both remote and in situ measurements are made of the atmosphere and ionosphere. MPAE members have conducted radar studies, performed active experiments in space, participated in many satellite missions, and contributed to the planning of national and international space initiatives.

Atmospheric research on trace materials in the stratosphere and troposphere is carried out under the leadership of P. Fabian; cryogenic experiments are conducted on balloons. A neon-cooled sampler is used to obtain large amounts of air (about 8 to 10 L at STP) at several altitudes along the balloon track. After recovery, the samples are analyzed in the laboratory to determine the stable gas species present at different altitudes between about 10 to 35 km. Halocarbons are of major importance, and measurements of methyl chloride (CH_3Cl) confirm that chlorine of anthropogenic origin predominates in the stratosphere. In another effort, measurements of NO_x radicals are made because of their importance to the photochemistry of the ozone layer. Experimental results and model calculations have suggested that accepted values of the O_2 photo cross-section in the ultraviolet may be wrong by a factor of two, because this assumption is needed to explain other reaction rates and species abundances.

Especially in the last decade, radar has proved to be a powerful means of studying the upper atmosphere. MPAE has several successful radar-oriented research programs. Project SOUSY, involving P. Czechowsky, G. Schmidt, and others, is a program to study the structure and dynamics of the earth's atmosphere with very high frequency (VHF) radar at 50 MHz. Turbulence and wind velocity are determined below about 100 km, and investigations relate to topics such as global circulation patterns, planetary waves, and atmospheric tides.

J. Fejer, who has retired from MPAE and now works at the Arecibo Ionospheric Observatory (Puerto Rico), helped motivate the major MPAE research program on active modification experiments of the polar ionosphere. The work is conducted by P. Stubbe, H. Kopka, and others in collaboration with several European groups. The approach is to use powerful ground-based transmitters to heat and thereby modify the ionosphere. In addition to producing temperature and density modifications, the technique is uniquely suited to studying the behavior of ionospheric plasma instabilities generated by the high frequency waves that produce heating. Similar experiments have been performed in the US at Boulder, CO, at Arecibo, and in the USSR.

The MPAE work is done at the ionospheric heating facility near Tromso, Norway, built in cooperation with the Univ. of Tromso. The facility consists of 12 transmitters, each capable of generating continuous wave power of up to 125 kW in the frequency range of 2.5 to 8 MHz. The range is suitable for disturbing the ionosphere at altitudes ranging from the D region into the F region. Because of its high geomagnetic latitude (67.1°N),

experiments at Tromso give results complementary to those from Boulder (mid latitudes) and Arecibo (low latitudes).

Although many experiments have been performed with the heating facility, the program is only in its infancy. Measurements have been made on D region modifications, polar electrojet modulation at different frequencies, backscatter from field-aligned plasma irregularities, stimulated ionospheric wave emission, absorption due to the parametric decay instability, and other effects. Among the planned experiments are simultaneous observations from the Tromso heating facility with the STARE and EISCAT radar systems.

The Scandinavian Twin Auroral Radar Experiment (STARE) consists of two coherent, pulsed radars--one in Norway operating at 140 MHz and one in Finland at 143.8 MHz. Each radar has a broad beam transmitting antenna with a common field of view of 400 × 400 km in the E region ionosphere above northern Scandinavia. Narrow beam receiving antennas provide a spatial resolution of 20 × 20 km. In 1977, R.A. Greenwald (now at the Applied Physics Laboratory, The Johns Hopkins Univ.) built the facility and began MPAE's research on the STARE system. Recent efforts at MPAE continue under E. Nielsen in collaboration with European and American groups. A system similar to STARE but at lower latitudes, called SABRE (Swedish and British Radar Experiment), has been built and is operated by groups at the Univ. of Leicester (UK) and the Uppsala Ionospheric Observatory (Sweden).

STARE and SABRE measurements determine ionospheric electron velocities and electric fields. Because of the large field of view and grid point resolution, spatial and temporal variations can be distinguished to provide more detailed dynamical interpretations than usually are possible with satellite measurements. The continuous measurements from STARE are particularly valuable when analyzed along with simultaneous measurements from other experiments--such as ground-based magnetometers, auroral imaging, riometers, and magnetospheric satellite measurements. An example is the analysis of how STARE results relate to properties of the geomagnetic and interplanetary magnetic fields (Scourfield and Nielsen, 1981). In another study, STARE observations were correlated with TRIAD satellite observations of magnetic perturbations to investigate the relationship between field-aligned-currents, known as Birkeland currents, and pulsations.

In recent years, the space physics community has assigned high priority and devoted a great deal of effort to identifying and studying ionospheric-magnetospheric coupling processes. Electric fields and the nature of Birkeland currents are of fundamental importance. Radar measurements determine ionospheric parameters that are needed in model calculations of ionospheric currents and electric fields. Present models of the ionosphere are limited by current knowledge of Birkeland currents and by the structured features of the ionospheric conductivity. Radar measurements are uniquely suited to providing input information for the models and verifying many calculated outputs of the models. STARE and other radar facilities have contributed to this synergistic relationship between observation and theory.

The European incoherent scatter (EISCAT) radar project has been established to study processes in the upper atmosphere at high latitudes. The EISCAT facility, which is not yet fully operational, will be described in a future EOS article. The EISCAT system includes several radars that operate at VHF and ultrahigh frequencies (UHF). The UHF measurements determine the velocity (all three components) of the ionospheric plasma, and the VHF system probes to high altitudes over a wide span of latitudes. MPAE has several planned initiatives for EISCAT, including joint campaigns with STARE and the GEOS satellite. Recently, Jürgen Röttger of MPAE became the associate director of the EISCAT program.

Earth and planetary studies in magnetospheric physics are well established at MPAE. V.M. Vasyliunas is a leading theorist in the field and has made major contributions in several areas. For example, he has specified a self-consistent scheme for ionospheric-magnetospheric dynamics that encompasses almost all models in use or development today. Vasyliunas is known for his important work on magnetic reconnection theory, the dynamics and morphology of Jupiter's magnetosphere, comparative magnetospheres, and many other topics. He is also an editor's delight as a thorough, knowledgeable, and prompt referee. Such qualities and his encyclopedic knowledge of the literature make him a desirable and prominent figure at professional society meetings. (This latter attribute similarly applies to Axford.)

Many MPAE scientists contribute to satellite experiments and instrument development for magnetospheric or

interplanetary studies. H. Rosenbauer has participated in several satellite missions (including ISEE, GEOS, and HELIOS) and is a principal investigator on the International Solar Polar Mission (ISPM) and on the GIOTTO mission to Halley's Comet, both scheduled for launch in 1985. Because of NASA's unexpected program cancellations in the project, an action that will affect the nature of future US-European space agreements, ISPM is predominantly a European Space Agency mission. Rosenbauer's work relates primarily to plasma measurements of the energy and composition of solar wind ions. Rosenbauer and E. Keppler are preparing an important experiment for ISPM. Using helium as a tracer, they plan to measure the presence of the neutral interstellar gas in interplanetary space. The work is being done in collaboration with the Univ. of Arizona.

Many MPAE scientists work with in-house teams or with other institutions on magnetospheric and interplanetary research. P.W. Daly has been active in the data analysis of satellite experiments from ISEE and HELIOS. One of his recent publications is on the important discovery of magnetic flux transfer events on the dayside magnetopause of Earth. W.-H. Ip is a theorist with recent work on comets, planetary rings, and asteroids. He has reported on the drift motion of charged particles in Jupiter's magnetosphere, including effects of the Io-plasma torus and on the atmospheric interactions of planetary bodies with the solar wind. K. Jockers has worked theoretically on force-free magnetic fields and lately has been involved with the physics of comets and work relating to the GIOTTO mission. H.U. Keller is principal investigator on the key imaging experiment of the GIOTTO mission.

E. Keppler has contributed to research and instrument development projects and has recently published a popular book in German: *Sun, Moons and Planets: What Occurs in the Solar System* (Piper Publishing, Inc.). E. Kirsch has emphasized research on substorms and planetary studies. He has collaborated with S.M. Krimigis (Applied Physics Laboratory, The Johns Hopkins Univ.) on results from the Voyager missions to Jupiter and Saturn. A. Korth has been active in analyzing GEOS satellite data, particularly in coordination with other data sets.

A.K. Richter is enthusiastic and a participant on several research projects. In recent efforts he has analyzed HELIOS solar wind particle data within the orbit of Earth, performed simulations of Alfvén waves in the interplanetary medium, and examined propagating shock waves. With W. Stüdemann, B. Wilken is immersed in instrument design and development work relating to several future missions (AMPTE, GALILEO, OPEN, and VIKING). Using time of flight techniques, the MPAE effort is to make plasma ion composition measurements at high energies. Wilken has participated on several satellite missions (GEOS, HELIOS, and ISEE) and auroral rocket efforts. Both Stüdemann and K. Wilhelm are involved with Space Lab electron experiments, with emphasis on both natural and artificially activated events.

The size of the MPAE staff is stable and includes 54 scientists and about 150 technical and support staff. In addition to the regular staff, 10 to 15 visitors are usually at MPAE. In-house technical and engineering capabilities are excellent. The machine shop is well equipped, and the technical staff does the necessary electronics and building of satellite experiments. The technical staff is quite burdened now because of MPAE participation in forthcoming missions such as GIOTTO and GALILEO.

Looking ahead, prospects at MPAE are exciting. Rosenbauer's neutral gas experiment on ISPM will open a new area of investigation on the interaction of the interstellar medium with the solar system. Keller's camera project on GIOTTO will provide the public with the most tangible scientific results on Halley's comet. The energetic particle experiments of Wilken and Stüdemann promise new results on several future missions, including GALILEO, VIKING, and eventually OPEN.

MPAE is headed by the directors--Axford, Rosenbauer, and Vasyliunas--who provide joint scientific leadership. The task of administrative leadership is rotated. Currently, Rosenbauer heads the administration, and the task next falls to Vasyliunas. Late in 1982, Axford began a 3-year leave of absence from MPAE and holds the post of vice chancellor at the Univ. of Wellington in New Zealand (a position equivalent to the presidency of an American university). In his absence, no replacement has been appointed, and the directorship of MPAE remains with Rosenbauer and Vasyliunas. The expectation is that Axford will return to MPAE; if so, the institute probably will continue its present course.

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E.L. Carovillano

STATISTICS

STATISTICS AT AACHEN

The Institute of Technology at Aachen is one of the foremost technical universities in the Federal Republic of Germany; it is particularly well known for its engineering departments. It has an active statistics department (the Institut für Statistik und Wirtschaftsmathematik), which grants several doctorates in statistics each year.

Prof. Burkhard Rauhut is head of the department. He is interested in a broad range of statistical applications, including sampling inspection, quality control, and inferences in the presence of outliers. For example, he is working on estimating the mean of an exponential distribution when an outlier may be present in the data. Several general approaches have been suggested; they involve variations in assumptions about the potential outlier. In one approach, it is assumed that one knows which observation might be the outlier, so a test can be performed to determine whether it should be rejected before using the remaining observations for estimating the mean.

A second approach is to take a Bayesian point of view in which all observations have, *a priori*, equal likelihood of coming from a second distribution with larger mean. Rauhut has considered the case where n-1 observations are a random sample from an exponential distribution with mean α, and one observation is from an exponential distribution with mean α/β for some nuisance parameter β between zero and one. He wants to estimate α using an estimator with "good" mean square error (MSE) qualities both when no outlier is present ($\beta = 1$) and when $\beta<1$. Rauhut adopts the terminology of Anscombe (1960) relating these goals to the qualities of an insurance policy: the "premium" of an estimator is the percentage increase in MSE over that of the standard (random sample based) estimator when in fact $\beta = 1$. The "protection" of an estimator is the percentage decrease in MSE of the estimator under that of the standard estimator in the nonhomogeneous case, usually calculated only for selected values of $\beta<1$.

The standard estimator for α in the homogeneous case is, of course, $T_0 = n\bar{x}/(n+1)$, which has $MSE(T_0) = \alpha^2/(n+1) + 2\alpha^2(1-\beta)^2/(n+1)\beta^2$. For $\beta \to 0$, $MSE(T_0) \to \infty$, which can be avoided by a suitable choice of estimator. Rauhut has evaluated the protections of several types of estimators of α having bounded MSE, subject to constraints on premiums. The "always trim" estimator is the simplest:

$$T_1 = \sum_{1}^{n-1} x_{(i)}/n,$$

where the $x_{(i)}$'s are order statistics of the sample $x_1, x_2, \ldots, x_n$. A second estimator is T_2, which Rauhut calls a "testimator" because it can be viewed as testing $x_{(n)}$ to determine which form of the estimator to use. T_2 is T_0 if $x_{(n)} - x_{(n-1)} < \kappa(x_{(n-1)} - x_{(1)})$ and is T_1 otherwise. The value of κ is selected to provide the desired premium. A second testimator, T_3, is T_0 if $x_{(n)} < \kappa\bar{x}$ and is T_1 otherwise. Rauhut has derived the MSEs of the estimators T_1, T_2, and T_3, and has calculated their protections for various fixed premiums (usually 1% or 5%) as functions of β and n. Comparisons of the protection levels lead him to conclude that whenever there is possibility of an outlying observation, the estimator T_3 is preferable to T_2, which in turn is preferable to T_1. With T_3, the possible loss in MSE for the homogeneous case is small compared with the possible gain if in fact $\beta<1$.

Rauhut and a colleague, Dr. O. Krafft, have been working on statistical quality control problems. One project involves assigning costs to the producer of various actions that might occur in the quality control framework, including costs of finding units defective during inspection, costs of having defective units returned from the consumer, and fixed and variable costs of conducting the inspection. Rauhut and Krafft have developed an interesting sampling plan for use when the lifetimes of the units in the lot being inspected are distributed as an exponential density with unknown parameter α which is translated by an unknown parameter γ. As this lot should be rejected if the fraction, p, defective is too large ($p>p_1$), it

follows that, equivalently, the lot should be rejected if $\hat{\gamma}+u\hat{\alpha}<T$, where $u = -\ln(1-p_1)$ and T is the pth quantile of the unit life distribution.

Rauhut and Krafft are thus led to consider sampling plans that call for rejection of the lot when $\hat{\gamma}+u\hat{\alpha} = x_{(1)}+(u-n^{-1})\hat{\alpha}$ is small enough. The latter expression can be given as a sum of independent, exponentially distributed, random variables, so an appropriate normal approximation can be used to find approximate critical values and operating characteristics for the test. It is also possible to investigate what sample size, n, should be used. Subtracting the "unavoidable costs" (the least possible costs with zero sample size) from the expected costs for accepted and rejected lots gives the expected "regret," $R(p,n)$, for the sampling plan. The Aachen team has derived expressions for n that minimize the maximal (over p) regret. It turns out that the expressions are rather intractable, so approximations for the sample size requirement are being developed.

Several people at Aachen are working on problems associated with statistical extremes. Dr. Rudolf Mathar has been investigating characteristics of the tails of a distribution and their connections with existence of moments. Suppose $\{X_n\}$ is a sequence of independent random variables, each distributed in accordance with the cumulative distribution function (CDF) F (i.e., the X's are IID F) where $F(x) = 0$ for $x<a$ and $F(x)<1$ for all x. Let $X_{i,n}$ denote the ith order statistic of $X_1, X_2, \ldots, X_n$. Green (1976) defined absolute and relative outlier resistance and proneness of F in terms of the asymptotic behavior of the difference and ratio of $X_{n,n}$ and $X_{n-1,n}$. Mathar has shown that these characteristics can be equivalently defined in terms of the ratios

$$q(x;\varepsilon)=[1-F(x+\varepsilon)]/[1-F(x)],$$

$$r(x;\varepsilon)=[1-F(\{1+\varepsilon\}x)]/[1-F(x)].$$

Thus, a distribution F is absolutely outlier resistant if, for any $\varepsilon>0$, $q(x;\varepsilon)\to 0$ as $x\to\infty$; absolutely outlier prone if there are $\varepsilon>0$ and $\sigma>0$ such that, for any x, $q(x;\varepsilon)>\sigma$; relatively outlier resistant if, for any $\varepsilon>0$, $r(x;\varepsilon)\to 0$ as $x\to\infty$; and relatively outlier prone if there are $\varepsilon>0$ and $\sigma>0$ such that, for any x, $r(x;\varepsilon)>\sigma$. According to Mathar, the outlier behavior of F, characterized by the tail of F, can be completely determined by investigating $q(x;\varepsilon)$ and $r(x;\varepsilon)$. For example, he has shown that F is absolutely outlier prone if $\ln[1-F(x)]$ is convex for x sufficiently large. The existence of moments of F is also related to these concepts. Mathar has shown that $E(X^\kappa)<\infty$ if F is relatively or absolutely outlier resistant (but not conversely). On the other hand, if F is relatively outlier prone, then high-order moments do not exist.

Dr. Dietman Pfeifer is working on determining distribution characteristics of record times and inter-record times. As before, let $\{X_n\}$ be a sequence of IID F random variables, where F is continuous. The sequence $\{\Delta_n\}$ of inter-record times consists of the random numbers of observations between successive record high values in $\{X_n\}$;

$$\Delta_0 = 1;\ \Delta_{n+1} = \min\{k: X_{U_n+k} > X_{U_n}\}$$

where $U_n = \Delta_0+\Delta_1+\ldots+\Delta_n$ defines the sequence $\{U_n\}$ of record times and $\{X_{U_n}\}$ is the sequence of record values.

It is well known that Δ_n and U_n have no first or higher order moments. It is also well known that the distribution of Δ_n is independent of F, so one can assume any convenient continuous cumulative distribution function in a study of the Δ_n. Pfeifer assumes $F(x) = 1-e^{-x}$; $x>0$, in which case X_{U_n} is distributed gamma with mean $n+1$. Using this framework, he has obtained very good asymptotic expressions for low order moments of $\ln(\Delta_n)$ and $\ln(U_n)$. Specifically,

$$E(\ln\Delta_n) = n-C+O(n/2^n),$$

$$V(\ln\Delta_n) = n+\pi^2/6+O(n^2/2^n),$$

$$E(\ln U_n) = n+1-C+O(n^2/2^n),$$

$$V(\ln U_n) = n+1-\pi^2/6+O(n^3/2^n),$$

all as $n\to\infty$. Here, E stands for mean value, V denotes variance, $C\approx.5772$ is Euler's constant, and $O[h(n)]$ is a function of n such that the sequence $O[h(n)]/h(n)$ is bounded.

The above expressions give a remarkably clear impression of the growth behavior of record and inter-record times as n gets large. Surprisingly, $V(\ln U_n)<V(\ln\Delta_n)$ for large n, in spite of the fact that U_n =

$\Delta_n+\Delta_{n+1}+\ldots+\Delta_0$. Rényi (1962) showed that both $(\ln\Delta_n-n)/\sqrt{n}$ and $(\ln U_n-n)/\sqrt{n}$ are asymptotically normally distributed, although with these normalizing constants the convergence is so slow that approximations with finite n are not particularly good. Pfeifer comments that use of the above expressions for mean and variance, with the "O" terms dropped, gives asymptotic normal sequences in which the convergence is much more rapid. In turn, this gives much improved approximations for finite n.

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D.E. Barr

NEWS & NOTES

EURECA: A PLANNED EUROPEAN LONG-DURATION SPACE PLATFORM

The Space Shuttle is truly an American facility with a central role in much of our national space program for the next decade--but it is also significantly influencing the planning of the European space program. A recent example is the call that the European Space Agency (ESA) issued to member states for experiments to be carried out on the European Retrievable Carrier (EURECA).

EURECA will be a reusable, free-flying platform that will be launched and retrieved by the Space Shuttle. The first mission of EURECA is planned for 1987 and will be committed primarily to microgravity research. EURECA will have a near-circular orbit at 500 km, with an inclination of 28.5 degrees. The flight duration will be 6 months, and gravity will be at 10^{-5}g below 1 Hz. The priorities set for the first flight reflect the attraction of the space environment for conducting fluid, materials, and biological studies. The planned experimental hardware includes furnaces and thermostats, and will accommodate investigations such as the processing of metallurgical samples, crystal growth from the melt or from solution, plant growth, protein crystallization, and radiobiological experiments. Only about 10% of the first payload will be available to the more familiar disciplines of space science and technology, which will be given greater opportunities in subsequent EURECA missions.

The total orbital payload of EURECA will be 1000 to 1200 kg, of which about 70 to 80% will be taken up by the core payload. About 200 kg will be available to proposed experiments in materials science and the life sciences, and an additional 100 kg for experiments from other disciplines.

The core payload will be funded and developed by ESA and will include six multi-user facilities: an automatic monoellipsoid mirror furnace facility that will handle about 25 samples and achieve temperatures up to about 1000°C; a solution growth facility consisting of three modules, each with four reactor vessels operating under isothermal or controlled thermal gradient conditions; a protein crystallization facility that will include 12 experimental modules and a video camera to observe crystal growth; a multi-furnace assembly to accommodate about 30 furnaces, particularly for materials science experiments; an automatic gradient heating facility that can provide gradients of less than ±1°C/cm at 1000°C for a 10-cm sample; and a botany facility that will accommodate a variety of experiments.

The funding ESA has approved for the EURECA project is conditional and includes spacecraft development, preparation and spacecraft integration of the multi-user core payload, and launch and retrieval operations. The multi-user facilities will be developed if the call for experiments elicits a satisfactory scientific response. Consideration, but not development funding, will be given to experimenters who propose projects not using the core payload. The deadline for submitting proposals to ESA is 30 April 1983.

R.I. Carovillano

THE GERMAN SPACE PALLET SATELLITE

The US Space Shuttle has been designed to launch satellites from space

orbit and to retrieve them. The first satellite launches from space took place successfully during the most recent flight (STS-5) of the orbiter Columbia. The first retrieval effort is scheduled for STS-7, planned for launch in April or May 1983 on the orbiter Challenger. STS-13 will be the first repair mission, an elaborate effort that will restore the Solar Maximum satellite.

The German Space Pallet Satellite (SPAS-01) will be the first spacecraft to be orbited and retrieved by the Shuttle. The satellite is large (4.2-m long and about 2 m^2 in cross-sectional area), massive (1800 kg), and has a modular design to accommodate various subsystems and experiments. SPAS-01 is a recoverable and reusable spacecraft privately financed by the German company Messerschmitt-Boelkow-Blohm (MBB). MBB will have spent about $14 million for the satellite through the first launch and an additional $10 million for on-board experiments. NASA, the German government, and the European Space Agency (ESA) will commit additional funds and services to accomplish the launch. ESA plans to provide about $155 million to continue developing the SPAS project with MBB in connection with the European Recoverable Carrier (EURECA) program.

The SPAS-01 spacecraft will be carried on a Boeing 747 to the Kennedy Space Center for launch. When in orbit, SPAS-01 will be stationed in the open cargo bay of the Shuttle for about a day and then placed in orbit. SPAS-01 will be deployed and retrieved by the Shuttle manipulator arm that has been tested in earlier flights. The satellite will have a 10-hour free flight, during which the Shuttle crew will practice approaches and recovery maneuvers. SPAS-01 is reusable and expected to survive many launches. Design changes may permit SPAS to remain in orbit for a month or more, as EURECA would require, and to be used for geostationary projects. SPAS-01 will have a simple gas propellant system to provide attitude control, and this would be greatly upgraded by a rocket propulsion system in future designs.

R.L. Carovillano

INFORMATION ON OFFSHORE OPERATIONS

The Offshore Information Conference held in Aberdeen, Scotland, in September 1982 focused on four topics concerning the offshore oil industry:

1. Marine pollution documentation.
2. Infoil II, a joint venture between Norway and the UK to establish a cooperative data base on current research projects of interest to the offshore oil industry.
3. Technical information services available on the offshore platform itself.
4. Scandinavian data bases for geological, oceanographic, and meteorological data.

The conference papers are available from:

Arnold Myers, Information Officer
Institute of Offshore Engineering
Heriot-Watt University
Edinburgh EH14AS, Scotland
Telephone: 031-449-5111

The papers cost £9.50, including international mail postage, or £10.50, including international airmail charges.

Mr. Myers is also the source for the *IOE Library Bulletin*, a monthly document giving information about publications dealing with offshore engineering. Subscriptions are £21.00 a year.

D. Mott

IT 82 A PUBLIC RELATIONS COUP IN BRITAIN

Britain's Information Technology Year--1982 created an explosion of interest in the computer's potential, according to Kenneth Barnes, head of the IT 82 project office.

Speaking at a London meeting of the Institute of Scientific and Technical Communicators, Barnes said that the prime objective of the campaign was to make all sectors of the community more sensitive to the benefits and opportunities offered by information technology. The year-long blitz of advertisements, television specials, and displays at shopping malls attempted to show how information technology will increasingly affect people's lives. At exhibits around the country, people were introduced to programming, word processing, and electronic mail.

According to surveys taken near the beginning of IT 82, only 17% of Britain's population had heard of information technology; by November 1982, that figure had increased to 62%. Barnes said that the most critical job

for the future will be adult education. All managers and employees will not have to know how to operate a computer, but they will need to know how to apply the technology so that it meets a business' needs.

IT 82 cost £6 million (about $11 million); the bill was picked up by the British government and private industry.

L.F. Shaffer

UK's MICROPROCESSOR LITERACY INCREASES

The effects of the Microprocessor Awareness Program sponsored by the UK Department of Industry are beginning to be felt throughout the world. Microprocessor literacy in Britain is certainly higher than that of any other European nation; weekly BBC TV educational broadcasts of microcomputer fundamentals and applications contribute enormously to this achievement. Britain now accounts for 45% of all personal computers sold in Europe. Since 1977, 10,000 new UK companies have become consumers of semiconductors used in manufacturing their products. In fact, computer literacy is increasing so quickly that the UK is now the largest user of semiconductor memory in Europe. By the end of 1983, The UK is expected to replace West Germany as Europe's largest user of semiconductors. It would appear that no country has seen more clearly than Britain the potential of microcomputers.

M.N. Yoder

INDIA PLANS VLSI SUPPORT

Information Technology is "it" for the eighties--as more and more nations view IT as their economic messiah. India is the latest country to formulate plans for very large scale integrated (VLSI) circuit support. According to *Electronics Weekly* (23 February 1983), an Indian government task force has proposed a 2,300 million rupee (Rs) (about $230 million) plan for "providing a viable and self-sustaining technological base for microelectronics in the country." To implement the program in a coordinated and integrated manner, a national microelectronics council is to be organized. The task force also recommended establishing a center of excellence for gallium arsenide integrated circuit technology funded at about the same level as the VLSI effort.

Indian electronic systems requirements probably will reach Rs 50 billion by 1990, with integrated circuits expected to play critical roles.

M.N. Yoder

LASER EYE-TESTING MACHINE

A new machine could revolutionize the prescription of simple eyeglasses. Invented by Maroof Abul-Karim of the Military Technical College in Baghdad and now being produced at Scientifica-Cook Ltd. in London, the device focuses a laser beam on a rotating cylinder. To the observer who is looking at the reflected light, a speckled image appears. A person is farsighted if the "grain" of the image appears to move upward, and nearsighted if the image moves downward. Sideways movement implies astigmatism. To correct farsightedness or nearsightedness, a spectacle lens that will "stop" the motion in the speckled display is selected. The whole procedure takes only a few minutes and is harmless. (Astigmatic patients are referred to an optometrist or ophthalmologist.)

Vision specialists are expected to greet the new machine with some reserve; for instance, such machines cannot indicate diseases in the eye. However, the device may have real promise for mass screening programs where individual examinations by a professional are not practical. Its testing rationale deserves a careful critique from the optometric and ophthalmological communities.

N.A. Bond, Jr.

SURVIVAL IN A COLD SEA

According to Russian sources, an airman, V.V. Smagin, ejected into the White Sea last September and survived severe weather and water conditions for 7 hours. Just before ejection, the airman noted radio reports on the weather: heavy rain; winds gusting to 18 m/s; sea state 5 or 6; water temperature, 6°C; air temperature, 5°C.

After parachuting into the water, Smagin inflated his life raft and began rowing with the wind, which he presumed was toward shore. Waves overturned the raft several times, but Smagin was able to right the raft and keep rowing. He reached shore just before losing consciousness; his landing roused some dogs, and their barking led to his rescue. Official manuals predict death within an hour in such sea and weather conditions. Smagin's persistent rowing must have been a key element in this remarkable case of cold-water survival.

J.A. Bond, Jr.

SCALED IMPACT EXPERIMENTS ON CONCRETE STRUCTURES

For the past 4 years, the UK Atomic Energy Establishment (AEE) at Winfrith, Dorset, has been studying the effects of hard and soft impacts of missiles on reinforced concrete wall structures. Such impacts could pose significant risks at a nuclear power facility.

Hard, mechanical impacts could accidently occur within the facility--from missiles such as the metal fragments of an exploding over-stressed pressure vessel or a runaway generator. Soft, external impact would occur, for example, if an aircraft crashed into the facility (i.e., a military combat jet rather than a large passenger or cargo plane). Such an impact is "soft" because the aircraft's crushable forward section cushions the momentum transfer. Impacting velocities up to 250 m/s are of interest.

A major objective has been to develop and validate a constitutive model for the dynamic behavior of reinforced concrete. A finite difference code has been tested in association with the UK Atomic Energy Authority, Safety and Reliability Directorate, Culcheth. Currently, four AEE engineers and scientists (plus support staff) are assigned to the missile impact project, and over 300 experiments have been done. The leader of the project is Dr. Peter Barr, who is also chairman of the UK Atomic Energy Authority's Missile Study Working Group. The group includes representatives from the Nuclear Installations Inspectorate, the National Nuclear Corporation, British Nuclear Fuels Limited, British Gas Limited, the Central Electricity Generating Board, and the Health and Safety Executive. The AEE also collaborates internationally with the French, Germans, and Scandinavians.

Early in their investigations, the AEE scientists determined that reliable results are obtained from experiments done on a replica scale in which the dimensions of the targets and missiles are reduced, but the impacts take place at full speed. For impacts at low velocities, the AEE uses a drop-weight system, and for higher velocities it uses a specially built compressed air cannon. The cannon has a bore of 150 mm (fitted with sleeves for smaller missiles), and impact velocities up to 300 m/s can be achieved with missiles weighing tens of kilograms. High speed cameras (to 10,000 frames/s) and a complete system of strain and load gauges on the targets and support structures are used to record and measure the impact events. (Note: In one set of collaborative experiments, a 600-mm cannon at the Bundeswehr experimental establishment, Meppen, Germany, was used to study the impact of missiles weighing about 1,000 kg, traveling up to 300 m/s, and giving 45 mJ of kinetic energy.)

Except for certain contract work of commercial competitive value, all the results of the AEE impact experiments have been published in the open literature (e.g., the *Nuclear Energy Journal*) or reported in the proceedings of the biannual Structural Mechanics in Reactor Technology (SMIRT) conferences. The next SMIRT conference will take place from 22 through 30 August 1983 at Argonne, IL. Another conference of interest is Recent Advances in Simulation of Impulsive and Impact Loading, to be held from 3 through 7 July 1983 at St. Peter's College, Oxford (contact T. Maini, Principia Mechanica Ltd.).

The present AEE program of impact experiments, limited to flat, reinforced concrete panel targets, will continue for 1 year. Future plans are to consider factors such as prestressing, curved structures, and special steel linings. A recent program of missile impact tests on steel piping is to be continued.

R.W. Booker
R.W. Armstrong

ONR COSPONSORED CONFERENCES

ONR London can nominate two registration-free participants in the conferences it supports. Readers who are interested in such participation should contact the Chief Scientist, ONR London, as soon as possible.

First UK Solar Maximum Mission (SMM) Workshop, Oxford, UK, 9-12 April 1983.

International Conference on Insulating Films on Semiconductors, INFOS 83, Eindhoven, The Netherlands, 11-13 April 1983.

Conference on Magnetic Resonance Spectroscopy of Liquid Crystals and Biological Membranes, Leeds, UK, 18-20 April 1983.

European Specialist Workshop on Active Microwave Semiconductor Devices, Maidenhead, UK, 4-6 May 1983.

International Symposium on Phase Relationships and Properties in Multicomponent Polymer Systems, Capri, Italy, 30 May - 3 June 1983.

NATO ASI on Physics of Submicron Semiconductor Devices, Pisa, Italy, 10-23 July 1983.

8th European Symposium on Fluorine Chemistry (ESFC-8), Jerusalem, Israel, 21-26 August 1983.

International Conference on Electronic Properties of Two-Dimensional Systems, Oxford, UK, 5-9 September 1983.

Microcircuit Engineering 83 Conference, Cambridge, UK, 26-29 September 1983.

16th European Conference on Laser Interaction With Matter, Imperial College, London, UK, 26-30 September 1983.

ONRL REPORTS

To request reports, check the boxes on the self-addressed mailer and return it to ONRL.

C-2-82: *Second Conference on Semi-Insulating III-V Materials*, by S.G. Bishop and E.M. Swiggard. The Second Conference on Semi-insulating III-V Materials dealt with four main issues: growth of bulk III-V crystals, assessment of high resistivity materials, behavior of high resistivity materials under heat treatments, and problems of III-V devices related to the semi-insulating conditions.

C-1-83: *Ion Formation From Organic Solids*, by R.J. Colton. The second international workshop on Ion Formation From Organic Solids provided a general review of the field, and dealt specifically with ion formation processes and applications.

C-2-83: *NATO/London Mathematical Society Advanced Study Institute on Systems of Nonlinear Partial Differential Equations*, by R.L. Sternberg. Major topics at the conference included problems in nonlinear elasticity, applications of bifurcation to mechanics, analysis and computational fluid dynamics, nonelliptic problems and phase transitions, and dynamical systems and practical differential equations.

R-1-83: *Robot Manipulator Control*, by J.F. Blackburn. This report presents a synthetic approach for calculating the control of robot manipulators. The initial control problem is broken down into linear control and modelling problems. The approach allows derivation of numerous schemes (adaptive or not) of control proposed in the literature and suggests new schemes. It is shown that the problem of modelling is difficult but is less crucial if one can synthesize robust controls that are not sensitive to errors of modelling.

EUROPEAN VISITORS TO THE US SUPPORTED BY ONR LONDON

Visitor	Affiliation	Organization to be Visited
Prof. H.C.A. Dale	Ergonomics Research Group Univ. of Hull 26 Newland Park Hull HU5 2DW	Navy Personnel Research & Development Center, San Diego, CA (27-29 June 1983) Aviation Psychology Lab Ohio State Univ. (4-6 July 1983) Wright-Patterson AFB (4-6 July 1983)
Dr. R. Huber	Hochschule der Bundeswehr München Neubiberg, FRG	CNA, Alexandria, VA NPG School, Monterey, CA (June 1983)
Mr. C.E.C. Wood	General Electric Company, Ltd Hirst Research Centre East Lane Wembley Middlesex HA9 7PP	NRL, ONR (24-25 May 1983) Cornell Univ. (27 May - 18 June 1983) Univ. of Vermont (20-24 June 1983)


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